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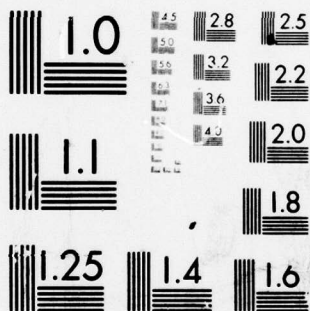
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TECHNICAL REPORT GL-79-20

INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING SAND-GRID CONFINEMENT AND MEMBRANE REINFORCEMENT CONCEPTS

Report I

SAND TEST SECTIONS I AND 2

by

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U. S. Army Engineer Waterways Experiment Station
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November 1979

Report I of a Series

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Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project 4A762719AT40, Task Area CO,
Work Units 001 and 004

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report GL-79-20	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INVESTIGATION OF BEACH SAND TRAFFICABILITY EN- HANCEMENT USING SAND-GRID CONFINEMENT AND MEM- BRANE REINFORCEMENT CONCEPTS. Report 1. SAND TEST SECTIONS 1 AND 2.		5. TYPE OF REPORT & PERIOD COVERED Report 1 of a Series
7. AUTHOR(s) Steve L. Webster		6. PERFORMING ORG. REPORT NUMBER
8. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		8. CONTRACT OR GRANT NUMBER(s)
9. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 4A762719AT40 Task Area CO, Work Units 001 and 004
11. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE November 1979
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 132
14. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15. SECURITY CLASS. (of this report) Unclassified
15. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. SUPPLEMENTARY NOTES		
17. KEY WORDS (Continue on reverse side if necessary and identify by block number) Beach sands Beach trafficability Expedient surfacings Grid confinement Membranes (Beaches)		
18. ABSTRACT (Continue on reverse side if necessary and identify by block number) Containerization of Army cargo for use in overseas theater of operations is progressing. The discharging of containers from containerhips and moving them across beaches in logistic over-the-shore operations is a problem that the Army must be capable of handling. The objective of this study was to investigate sand-grid confinement and membrane reinforcement concepts for possible application in moving containers over unstable beach sands using wheeled vehicles such as the XM 878 truck tractor and XM 872 semitrailer. In particular, it was (Continued)		

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20. ABSTRACT (Continued).

desired to determine the optimum grid cell size and minimum surfacing requirements for handling the over-the-shore container operations. A secondary objective was to test the potential use of buried membrane as expedient means for enhancing truck-semitrailer trafficability over beach sands. Two test sections containing a total of 14 test items were constructed and subjected to truck traffic. The tests included three membrane reinforcement items, 10 sand-grid confinement items, and one control item. Also tested in conjunction with the test items were four expedient-type surfacings. Test results showed that aluminum grids with a 6-in. cell size, 8 in. thick, filled with an unstable type beach sand, and surfaced with a spray application of SS-1 emulsified asphalt withstood 5000 passes of heavy truck traffic with less than 2 in. of permanent depression at the grid surface. Results also showed that two layers of T-17 membrane buried in unstable sand at 1- and 5-in. depths, respectively, and anchored from side pull-in can increase the trafficability of a loaded truck from 10 passes to more than 3500 passes before an 11-in. rut develops.

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PREFACE

This report was prepared as part of the work authorized by the Office, Chief of Engineers, U. S. Army, under "Mobility and Weapons Effects Technology," Project 4A762719AT40, Task Area CO, "Base Development in the Theater of Operations;" Work Unit 001, "Rapid Construction of Tactical Bridge Approaches;" and Work Unit 004, "Trafficability Enhancement Systems."

The investigation was conducted by personnel of the Geotechnical Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively. Personnel actively engaged in the planning and conducting of the investigation were Messrs. R. L. Hutchinson, A. H. Joseph, P. J. Vedros, S. L. Webster, and S. J. Alford. This report was prepared by Mr. Webster.

Directors of the WES during the conduct of the investigation and preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)

UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
kips (mass)	453.5924	kilograms
miles (U. S. statute)	1.609344	kilometres
mils	0.0254	millimetres
ounces (mass) per square yard	0.03390575	kilograms per square metre
pounds (force) per square inch	0.6894757	newtons per square centimetre
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per square foot	4.882428	kilograms per square metre
square yards	0.8361274	square metres
tons (2000 lb, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING
SAND-GRID CONFINEMENT AND MEMBRANE REINFORCEMENT CONCEPTS

SAND TEST SECTIONS 1 AND 2

PART I: INTRODUCTION

Background

1. Containerization of Army cargo for use in overseas theaters of operation is progressing. Container handling equipment is being purchased to provide a capability of handling breakbulk and the 8-ft*-wide and up to 40-ft-long family of containers weighing up to 50,000 lb. Under the program plan, a 50,000-lb capacity container handler will be used in conjunction with the yard-type XM 878 truck tractor and XM 872 triaxle semitrailer to move containers between shipside and a temporary storage yard within an approximate distance of 3 miles. The container operations will normally be conducted within port terminal areas having primary and improved secondary pavements; however, the discharging of containers from containerships and moving them across beaches in logistic over-the-shore operations is a real problem that the Army must be capable of handling.

2. Previous investigations conducted by the U. S. Army Engineer Waterways Experiment Station (WES) (Brown et al., 1972; Rush, 1974; Rush and Durham, 1975) have established useful information regarding surfacing requirements for various container-handling vehicles, field beach tests with off-road materials handling equipment, and summary data on worldwide beach and desert sand conditions. Also, the probable performance capability of a 50,000-lb capacity container handler was related to the worldwide beach and desert sand conditions.

3. Recent studies at the WES (Webster and Watkins, 1977; Webster and Alford, 1978) involving new construction concepts for pavements

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

across soft ground have yielded two concepts that might have application in beach sand trafficability enhancement. One concept uses sand-filled confinement grids to form a base layer capable of handling heavy truck traffic. The other concept uses a relatively high-strength membrane buried horizontally for reinforcement over unstable materials.

Objective

4. The objective of this study was to investigate the beach sand trafficability enhancement potential of the sand-grid concepts. In particular, it was desired to determine the grid cell size and minimum surfacing requirements for handling over-the-shore container operations using wheeled vehicles such as the XM 878 truck tractor and XM 872 semitrailer. A secondary objective was to test several buried membrane concepts and determine their potential as expedient means for enhancing truck-semitrailer trafficability over beach sands.

Scope

5. This investigation was limited to truck-semitrailer type traffic over beach sands. It did not include trafficability enhancement for the 50,000-lb container handling equipment. Their performance capability was studied by others (Rush, 1974; Rush and Durham, 1975). Two test sections containing a total of 14 test items were constructed and subjected to truck traffic. Included in the tests were three membrane reinforcement items, 10 sand-grid confinement items, and one control item. Also tested in conjunction with the 14 test items were four expedient-type surfacings. This report describes the materials used, the two test sections, the construction techniques, the tests conducted plus the results, an analysis of the results, and some conclusions and recommendations.

PART II: TEST SECTION 1

Description

6. Test sections were used to accomplish the objective of this study. The WES's past experience with road and airfield test sections has shown that test section performance was closely related to actual field performance. Also, when new concepts are used, the test section approach is useful in pointing out potential problems relating to construction techniques and allows for innovative adjustments or improvements to be tried. Both test sections for this study were located under shelter on the WES reservation. They were constructed over the shelter's firm floor, which consisted of compacted lean clay soil.

7. A plan and profile of test section 1 are shown in Plate 1. The test section was 20 ft wide and 240 ft long and consisted of eight test items, each approximately 30 ft long and 16 ft wide with 2-ft shoulders. The sand layer containing all test items was 20 in. deep. Ramps were installed at each end of the test section to allow test traffic to completely traverse all test items. Item 8 was a control item and consisted of compacted sand full depth. The sand was a local Vicksburg, Mississippi, sand used for the fine aggregate in concrete and hereafter referred to as "concrete sand." Item 7 contained two sections of T-17 membrane (each 16 ft wide and 30 ft long). The membrane was buried horizontally in the sand at 3- and 6-in. depths, respectively. Items 1-6 contained sand-filled grids. The grids in item 4 were 8 in. thick, and the grids in remaining items were all 6 in. thick. Items 1-4 contained aluminum grids with square-type cells, while items 5 and 6 contained paper grids with hexagonal-shaped cells. The grid cell sizes are indicated in the profile drawing in Plate 1. The wearing surface of all items was concrete sand. The thickness of the sand over the grid items ranged from approximately 1 to 3.5 in. and averaged 1.8 in. The surface of the east half of the test section was sprayed with a penetrating liquid asphalt to produce a sand-asphalt-over-sand surfacing for the east half

of the test section. The thickness of the sand-asphalt averaged 0.75 to 1.0 in.

8. After failure of item 6, test item 6A was constructed in its place. Item 6A consisted of one section of T-17 membrane (approximately 20 ft wide and 30 ft long) buried horizontally at a depth of 4 in. in compacted concrete sand. No sand-asphalt surfacing was used for item 6A.

Materials

Concrete sand

9. To represent the beach-type sand, a local Vicksburg sand that is the fine aggregate for concrete was used. Classification data for this sand are shown in Plate 2. The sand was a pit-run washed sand containing approximately 4 percent gravel sizes and no No. 200 material. It classified as a poorly graded (SP) sand. This sand was used because of its availability and free draining properties and because of past experience which showed that it would act similarly to many beach sands when subjected to rubber-tired traffic.

Aluminum grids for items 1-4

10. The aluminum grids used were fabricated at the WES from stock aluminum sheets (3 by 8 ft) 0.025 in. thick. First, several sheets of aluminum were stacked and sawed into 8-ft-long grid panels, each having a width equal to the desired grid thickness (either 6 or 8 in.), as shown in Figure 1. Next, the grid panels were stacked and held together by vise grips, while slots were sawed halfway down the panels at desired grid cell size intervals (Figure 2). Four-foot-long grid panels with matching slots were also made using the same procedure. The 8-ft-long panels were placed in a wood jig that aligned the panel slots such that inverted 4-ft-long panels could be inserted to form a 4- by 8-ft grid section having the desired cell size. Filament-reinforced adhesive tape was used to hold the panels together such that the completed grid sections could be folded flat for storage and handling or opened for usage without falling apart. Figure 3 shows grid sections opened for field placement along with a supply of folded grid sections (upper part



Figure 1. Cutting grid panels from stock sheets of aluminum

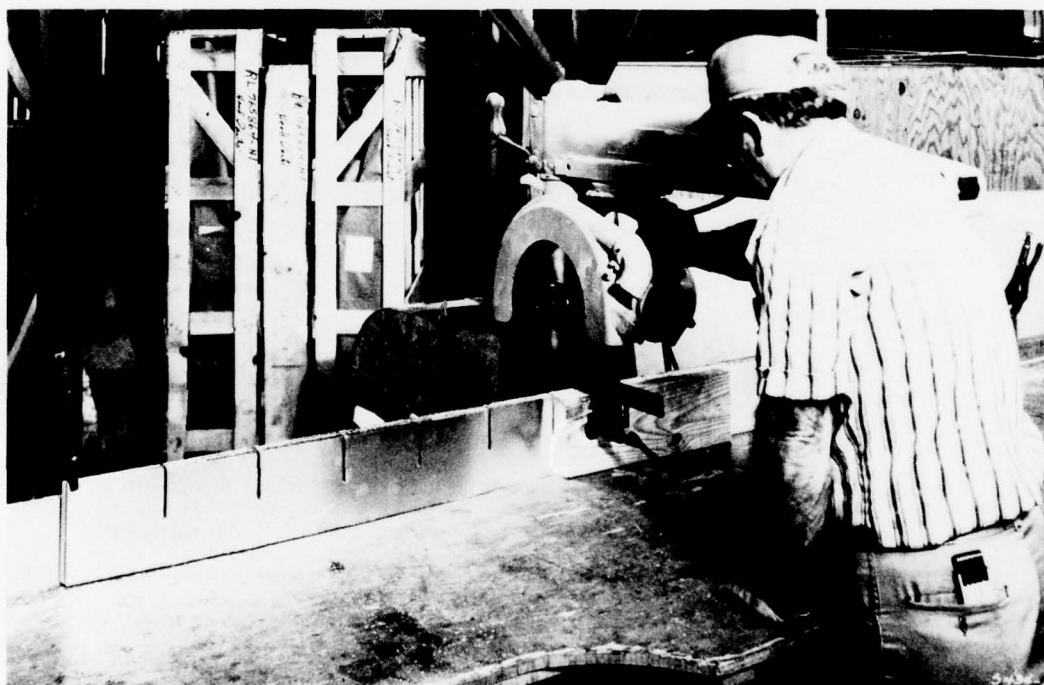


Figure 2. Cutting slots in grid panels



Figure 3. Folded and opened sections of grid

of Figure 3). Material and labor costs for the completed grids were approximately \$0.90 per sq ft of opened surface area for grids having a cell size of 6 in. and a thickness of 6 in.

Hexcel paper honeycomb grids

11. Paper honeycomb grids for testing were purchased from the Hexcel Corporation of Dublin, California. These honeycomb grids contained hexagonal-shaped cells that were formed by bonding sheets of Kraft paper that had been impregnated with a phenolic resin. The resin was to waterproof the paper so it would retain its strength properties in a wet environment. The paper honeycomb grids were supplied in a flat unexpanded condition. For field installation, the paper grids were pulled open by hand to the desired cell opening, and a few cells were filled with sand to anchor the grid in its expanded shape. Each expanded section of the paper grids covered an area 12 by 20 ft.

T-17 membrane

12. T-17 membrane is a neoprene-coated, two-ply nylon fabric designed to provide a waterproof and dustproof wearing surface for soil subgrades used as landing areas and roadways. The membrane consists of 54-in.-wide runs of the fabric joined together with factory-glued lap joints. The dimensions of the membrane can be varied to fit the area to be covered. The membrane weight is 0.33 psf.

RC 800 liquid asphalt

13. RC 800 is a rapid-curing cutback asphalt composed of asphalt cement and a naphtha or gasoline-type diluent. It is normally used for mixed-in-place pavement construction and surface treatment and penetration macadam applications. Upon exposure to atmospheric conditions, the diluents evaporate, leaving the asphalt cement as a binder material. Other available grades of rapid-curing liquid asphalts include RC 70, RC 250, and RC 3000. The lower numbers indicate more diluents used and, therefore, more penetrating ability and lower application temperatures (ASTM Designation: D 2028-76, 1978; AASHTO Designation: M 81-70, 1974).

Design

14. Test section 1 was designed for expedient construction. The current techniques for constructing sand-filled grids involve initial overfilling of the grids with sand so that construction equipment can operate on the sand-filled grids without damaging the grids. After compaction, the sand-filled grids have approximately 1 to 3 in. of excess sand surfacing. The west wheel path of the test section was used to test this excess sand as a wearing surface. The sand in the east wheel path was sprayed with RC 800 liquid asphalt and tested as an improved-type surfacing.

15. Test items 1, 2, 3, 5, and 6 were designed to allow study of grid cell size versus traffic performance. Items 5 and 6 would also establish field data on paper grids. Item 4 was included to help establish data on grid thickness requirements.

16. Since no data were available regarding buried membranes in

sand, item 7 was designed with a buried membrane at two elevations in the sand to determine benefits of this concept. Item 6A, which replaced item 6 after it failed, was installed to obtain performance data on one layer of buried membrane. A 20-ft-wide membrane was buried 4 in. deep in item 6A.

Construction

17. A 12-in.-thick layer of damp concrete sand was placed over an area 240 ft long by 20 ft wide. The sand was placed in two 6-in. lifts. A D-7 tractor was used to level and compact each lift. The surface of the sand layer was sprayed with water, and an attempt was made to obtain additional compaction of the sand using rubber-tired compaction equipment. A self-propelled rubber-tired roller could not pull itself through the sand even when the ballast was removed and tire pressure was reduced. Next, a towed-type roller (25,000-lb load on four tires with 50-psi tire pressure) was pulled over the sand layer. This resulted in rutting and shifting of the sand within the top 6 in. Some compaction probably occurred deep in the sand layer, but the top 6 in. was loose and rutted. The sand layer was then reshaped and compacted using the D-7 tractor. The tractor tracks in the sand were smoothed out using hand tools and a small vibratory plate compactor to produce the base layer of sand (Photo 1) on which all test items were constructed. The dry density of the sand base averaged 102 pcf, at an average water content of 4.8 percent.

Items 1-4 (square-type aluminum grids)

18. A crew of four men was used to install the aluminum grids on the prepared sand base layer. Grids for each item were folded and stacked on a pallet and delivered to the item site by a forklift. Two men would carry a folded section of grid onto the item, unfold it, and place it on half of the item as shown in Photo 2. A second two-man crew would then install a section of grid on the other half of the item as shown in Photo 3. A piece of Styrofoam board placed on the installed grids allowed one man to stand on the grid layer for ease in aligning

the interconnecting cells with neighboring grid sections. Strips of polyethylene sheeting were placed between the grid layer and sand base at selected intervals to aid in after-traffic data collection at the interface. Before installing grids in item 4, a 2-in. layer of base sand was removed to allow the surface of this thicker layer of grids to match neighboring grid items. Photo 4 shows an overall view of the installed grids.

19. A dump truck was used to back dump sand onto the grids as shown in Photo 5. A tractor then pushed the sand forward filling the grid cells as shown in Photo 6. The blade of the tractor was kept a minimum of 3 to 4 in. above the grid surface to provide a protective cushion layer of sand above the grids. One problem that developed when using this sand-filling technique was that the empty grids in front of the tractor tended to slide forward and bend out of shape when the tractor pushed a large quantity of sand forward or pushed the sand too fast. Photo 7 shows the results of grid movement during the sand-filling operations. This problem was easily solved by having a front-end loader fill and thus anchor a few grid cells along each side of an item.

20. After the grids were filled with sand, the tractor walked the entire surface as shown in Photo 8. The excess sand layer protected the grids as the tractor compacted the sand in the grid cells. Next, the towed-type roller (25,000-lb load on four tires with 50-psi tire pressure) was used over the grids (Photo 9). It was found that the roller could be used to compact the sand in the grid cells with no apparent damage to the grids. Some slight rutting did occur where there was an excess sand layer. A motor grader was used to obtain a smooth sand surface over the grids.

Items 5 and 6 (Hexcel paper grids)

21. A crew of eight men was used for installing the paper grids. Two groups of four men each faced each other and pulled uniformly on a section of unexpanded paper grids to open the cells. Caution had to be exercised because the glued joints between cells would easily tear when nonuniform pressure was used in expanding the grid cells. To prevent tearing of the grid cells, the 8-in.-size paper grids were only

partially opened 5 to 6 in. Photos 10 and 11 show closeup views of the 8- and 12-in. paper grids installed on the sand base layer.

22. The paper grids were filled with sand using the same technique as used for filling the aluminum grids. However, the towed roller and the motor grader could not operate on the sand-filled paper grids. Moisture from the sand had apparently weakened the paper, and severe rutting would occur under heavy tire loads. A small vibratory plate compactor was used for final compaction and surface smoothing of these two items.

Item 7 (T-17 membrane)

23. The base layer of sand was leveled and compacted at 6 in. below final grade as shown in Photo 12. Next, a 16- by 30-ft section of T-17 membrane was placed as shown in Photo 13. A 3-in. layer of sand was placed over the membrane, leveled, compacted, and a second section of membrane installed. A final 3-in. layer of sand was then placed over the second membrane, leveled, and compacted. Water was sprayed from a garden hose onto the sand layer each time the vibratory plate compactor was used.

Item 8 (control)

24. Construction was identical to item 7 except that no membrane was used.

Sand-asphalt surfacing over sand

25. The excess sand wearing surface for the grid items ranged in thickness from 1 to 3.5 in. As an attempt to improve this surfacing, the east half of the test section was hand sprayed with RC 800 liquid asphalt. Photo 14 shows the sand surfacing, which was still wet, being sprayed with asphalt. The temperature of the asphalt was 220°F as it was sprayed at a rate of approximately 1 gal per sq yd. Initial penetration of the asphalt into the sand was only 1/4 in. Photo 14 shows how the asphalt puddled at the surface of the sand. However, Photo 15 shows how most of the asphalt had penetrated into the sand after 24 hr. Final depth of penetration was 3/4 to 1 in. A light application of blotter sand was applied to the asphalt surfacing before traffic was applied. Grade RC 250 liquid asphalt would probably have penetrated

the sand faster and would have been a better choice than the RC 800 that was used.

Traffic Tests

Application of traffic

26. Test traffic was applied during May and June of 1978. Traffic was applied using the military 5-ton, M51, tandem-axle dump truck shown in Photo 16. A tire configuration for the XM 878 yard truck tractor and XM 872 semitrailer loaded with a 50,000-lb container and for the test vehicle is shown in Figure 4. Since the test vehicle had a lighter

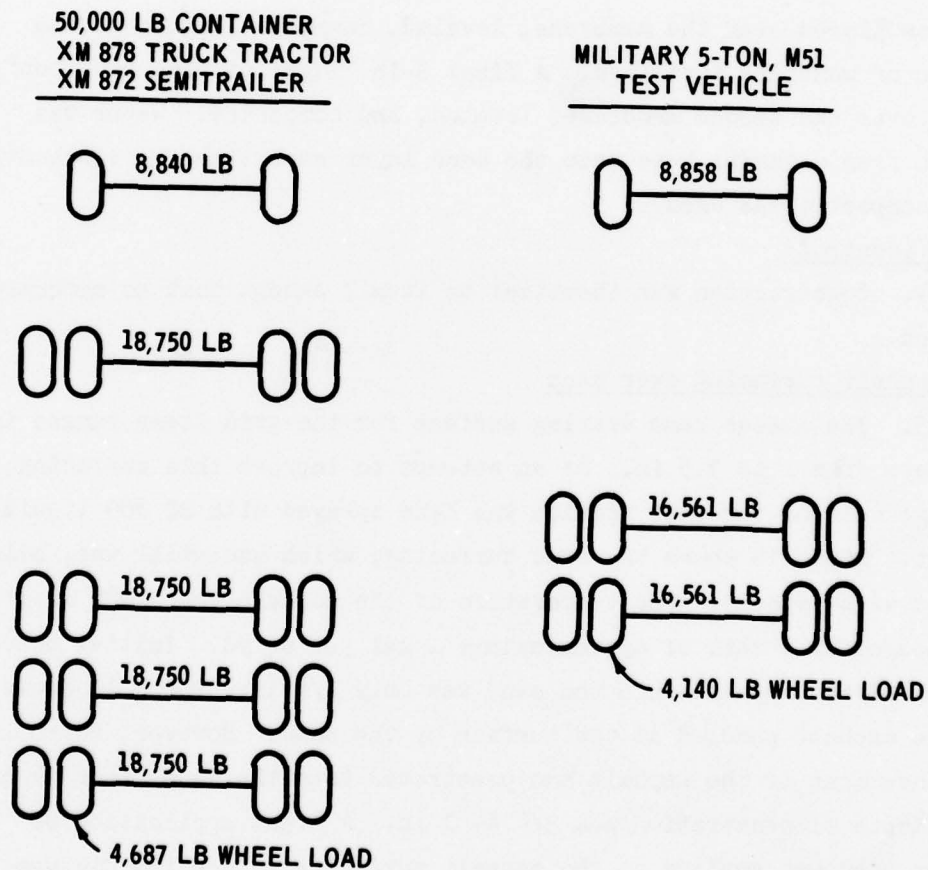


Figure 4. Tire configuration for the XM 878 truck tractor with XM 872 semitrailer and the military 5-ton, M51, test vehicle

wheel load and fewer wheels than the XM 878-XM 872 combination, it would require approximately 3.3 passes of the test vehicle to equal one pass of a loaded container vehicle. The 11x20, 12-ply tires were inflated to the recommended military highway tire pressure of 70 psi. The test section was trafficked as a one-lane road. The truck was driven forward and then in reverse over the entire length of the test section.

Tests and observations

27. Visual observations, photographs, and cross-section level readings were recorded at intervals throughout the traffic test period. After a wheel path had experienced severe rutting (9 in. or more), trenches were excavated across the wheel path to determine the condition of the test item materials. The performance of the test items and the data obtained are presented in the following paragraphs.

Item 1 (4-in.-square grids, 6 in. thick)

28. This item was the best performing item of test section 1. The sand surfacing averaged 1.5 and 1.8 in. thick in the west and east wheel paths, respectively. After only 10 passes of traffic, the rut depth in each wheel path was 4 in. Photo 17 shows the item after 500 passes of traffic. The east wheel path rut depth was 8.0 in., and the west wheel path rut depth was 7.7 in. Most of the rutting that resulted was due to lateral shifting of the surface sand out of the wheel paths. In the east wheel path, all of the sand that was originally between the sand-asphalt surfacing and grids (approximately 1 in.) had moved out to the edges of the wheel path, and the sand-asphalt surfacing was now resting on top of the grid cells. After 4850 passes of traffic (Photo 18), the average rut depths were 9.2 and 9.1 in. in the east and west wheel paths, respectively. The grids had sheared along the outside edge of the west wheel path exposing pieces of the aluminum grid. The sand-asphalt surfacing and sand-grid layer within the east wheel path appeared to be in good condition.

29. Traffic on item 1 was concluded at 4850 passes. Surfacing sand and a portion of the sand-grid layer were removed as shown in Photo 19. The sand-asphalt surfacing had settled within the top 1/2 in.

of the grid cells in the east wheel path. This surfacing protected the grids and allowed only 1/2-in. reduction in grid thickness to occur in the wheel path. (The minimum grid thickness was measured at three locations along the wheel path and averaged 5.5 in. as compared with the original thickness of 6.0 in.) The rut depth at the subgrade surface (bottom of the sand-grid layer) was 1.5 in. in the east wheel path. In general, the sand-grid layer in the east wheel path was in good condition and could have supported additional traffic.

30. The condition of the sand-grid layer of the west wheel path can be seen in Photo 19. The sand surfacing did not prevent traffic from damaging the surface of the sand-grid layer. The 4850 passes of traffic had bent the top 1.8 in. of the grid cells and thus reduced the grid thickness to 4.2 in. along the outside edge of the west wheel path. The subgrade rut was 1.7 in. in the west wheel path. The sand-grid layer was in poor condition, and the grids were disintegrating along the outer edge of the wheel path. The sand surfacing had allowed severe rutting to occur above the sand-grid layer and also did not adequately protect the surface of the grids from accumulated traffic wear.

31. Typical cross-section data for this item are shown in Plate 3. Traffic wander was approximately 18 in. The first few hundred passes of traffic approximately straddled the item center line. Later traffic tended to shift west with the bulk of the traffic applied with the center line of the truck approximately 18 in. west of the item center line.

Item 2 (6-in.-cubic grids)

32. The performance of this item was affected by the surfacing as well as the grid size. The sand surfacing in the west wheel path had an average thickness of 2.2 in. However, the sand-asphalt-over-sand surfacing in the east wheel path was much thicker and averaged 3.5 in. Since the sand-asphalt surfacing was 0.75 to 1.0 in. thick, approximately 2.5 in. of sand was between the grid surface and sand-asphalt surfacing. After only 10 passes of traffic, the rut depths were 7 and 5 in. in the east and west wheel paths, respectively. Photo 20 shows the item after 500 passes of traffic when rut depths were 10.8 and 9.3 in. for the east and west wheel paths, respectively. By 200 passes, the east wheel path

rut depth had increased to 11.8 in., and a piece of grid was observed lying flat in the wheel path. Test traffic on the east wheel path was concluded after 2000 passes. Photo 21 shows the east wheel path with the surfacing removed after 2000 passes. The tops of the grid cells were bent by traffic, and sand-asphalt was embedded within the bent cells. The average minimum thickness in the east wheel path was 3.3 in. A trench cut through the sand-grid layer revealed that the east subgrade surface had rutted 2.0 in.

33. Additional test traffic was applied to the west wheel path. Photo 22 shows the west wheel path after 2500 passes of traffic. Traffic on the west wheel path was concluded at this time. The average rut depth was 10.4 in. The tops of the grid cells were bent by traffic, and the average minimum thickness of the sand-grid layer was 3.8 in. The rut depth of the subgrade was 1.7 in. Typical cross-section data for this item are shown in Plate 4. It is interesting to note that the west wheel path that had a sand surface slightly outperformed the east wheel path that had a thicker surface consisting of sand-asphalt over sand.

Item 3 (8-in.-square
grids, 6 in. thick)

34. Performance of this item was poor. After 600 passes of traffic, the rut depths were 10.6 and 10.9 in. in the east and west wheel paths, respectively. The grids in both wheel paths were disintegrating rapidly, and pieces of grid material were found lying at the surface in each wheel path. Average minimum grid thicknesses were 1.5 and 3.1 in. in the east and west wheel paths, respectively. Typical cross-section data for the item are shown in Plate 5.

Item 4 (6-in.-square
grids, 8 in. thick)

35. The significance of item thickness was demonstrated by the performance of this item. The basic difference between this item and item 2 was the thickness of the sand-grid layer. The additional 2 in. of grid thickness in this item increased traffic performance by a factor of two. A total of 4850 passes of traffic was applied before an 11-in.

rut or noticeable grid disintegration developed. After 500 passes of traffic (Photo 23), both wheel paths had ruts approximately 9 in. deep. However, additional rutting developed very slow, and rut depths after 4850 passes of traffic were 10.1 and 11.0 in. in the east and west wheel paths, respectively. Photo 24 shows the condition of the sand-grid layer after 4850 passes. The average minimum grid thickness was approximately 6 in. in each wheel path. The rut depth at the subgrade surface was 1.5 and 1.3 in. for the east and west wheel paths, respectively. Plate 6 shows typical cross-section data for the item.

Item 5 (8-in. Hexcel paper grids)

36. Performance of this item was very poor. After 75 passes of traffic, the paper grids had totally disintegrated in both wheel paths. Even though the paper grids had been treated with a phenolic resin for waterproofing, the paper absorbed water from the wet sand and lost its strength. Typical cross-section data are shown in Plate 7.

Item 6 (12-in. Hexcel paper grids)

37. Only 10 passes of traffic were required to destroy the paper grids in this item and produce 11-in. ruts in both wheel paths. Typical cross-section data are shown in Plate 8.

Item 7 (two-layer T-17 membrane)

38. The trafficability enhancement potential from buried membranes was demonstrated early during traffic tests on this item. Photo 25 shows items 7 and 8 and a portion of item 6 after five passes of the truck. Notice the increased lateral movement of material (and thus deeper ruts) in item 6. Also, traction problems that occurred in item 8 did not occur in item 7. Photo 26 shows the item after 100 passes of traffic with rut depths of 6.4 and 6.6 in. in the east and west wheel paths, respectively. Notice how landing mat runners were used to repair failed items 6 and 8 so that traffic could continue on item 7. Photo 27 shows the item after 1000 passes of traffic. Rut depths were 9.3 and 10.1 in. in the east and west wheel paths, respectively. The center line of the truck traffic gradually shifted west as traffic was applied. By 1000 passes, the total westward shift was approximately 24 in. This westward wander of the traffic caused the top layer of membrane to pull

in from the west edge. By 1000 passes, the total west edge of the top membrane was lying in the west wheel path. Traffic was concluded at this time so that the condition and position of the membranes could be determined. Photos 28 and 29 show the top and bottom membranes, respectively, as cover sand was removed after 1000 passes of traffic. Both membranes were in excellent condition. Typical cross-section data are shown in Plate 9.

Item 8 (control)

39. The control item developed 12.5-in. ruts after only 10 passes of traffic. Photo 30 shows the control item along with a portion of item 7. Passes of traffic can be counted by observing the outer side of the west wheel path. Wheel slippage occurred during each pass of traffic. The thin sand-asphalt surfacing in the east wheel path offered no improvement in the performance of this item. Typical cross-section data are shown in Plate 10.

Item 6A (one-layer T-17 membrane)

40. After 100 passes of traffic on the test section, item 6A was installed to replace failed item 6. Item 6A consisted of one layer of T-17 membrane buried 4 in. in the sand. Photo 31 shows construction of this item using a 20- by 30-ft section of membrane. A 4-in. layer of cover sand and 20-ft width of membrane were chosen to help anchor the membrane along the sides of the wheel paths. Photo 32 shows item 6A prior to traffic.

41. Rut depths of 6 in. developed after 10 passes of traffic. After 400 passes (Photo 33), the rut depth had increased to 10.2 in. Wheel traction on the item was fair. The average rut depth increased to 11.1 in. after 900 passes of traffic. Traffic was concluded at this point, and the surfacing sand was removed from half the item to expose the position of the membrane (Photo 34). As traffic had progressed, it shifted westward a total of approximately 24 in. The results of the shifting traffic on membrane movement can be seen in Photo 34. Typical cross-section data for this item are shown in Plate 11.

Summary of Test Results

Passes versus permanent surface depression and rut depth

42. Plates 12-15 show plots of passes versus permanent surface depression (in the wheel path) and rut depth (permanent surface depression plus upheaval outside the wheel path) for test items 1-4, 7, and 6A for both wheel paths. These plots were developed from cross-section and rut measurements taken in each wheel path of the test items. The data points shown represent an average calculated from three locations (item quarter points) in each wheel path at the indicated pass level. The decreases in rut depth and permanent surface depression that resulted in items 7 and 6A (Plate 15) as traffic progressed were due to progressive lateral shift of the test vehicle wheels. As the number of passes increased, the center line of the test vehicle gradually shifted westward. The shift in traffic caused sand along the edge of the wheel paths to fall into the wheel paths. This resulted in a reduction in rut depth and/or permanent surface depression measurements.

Traffic test data

43. At the conclusion of traffic on each item, a test trench was dug across each wheel path, and cross-section measurements were obtained at the surface and bottom of the grids or on each layer of membrane. Rut depth and permanent depression values were then determined using the cross-section data. Also, the minimum grid thickness was measured at three locations (item quarter points) in each wheel path, and the average minimum grid thickness was determined. Tables 1 and 2 show the summary of traffic test data for the sand-grid and membrane items, respectively.

PART III: TEST SECTION 2

Description

44. Test section 2 was constructed over the base layer of sand used in test section 1. A plan and profile are shown in Plate 16. The test section was 16 ft wide and 150 ft long and consisted of five test items, each approximately 30 ft long and 16 ft wide. The sand layer containing grid items 1-4 was 20 in. deep over a width of 20 ft. The grids in items 1-3 were 8 in. thick, and the grids in item 4 were 6 in. thick. The grids used were the same type of aluminum grids as used in test section 1. The grid cell sizes are indicated in the profile drawing in Plate 16. The grids in the east half of the test section were filled with sand used as aggregate for mortar and hereafter referred to as "mason sand," and the grids in the west half were filled with concrete sand. The top 1 in. of all grid cells contained sand-asphalt to serve as the wearing surface. In addition, item 1 contained an asphalt-fabric membrane wearing surface. Item 5 was a membrane item, and it consisted of two layers of T-17 membrane buried in concrete sand and nailed to 4- by 4-in. timber runners as shown in section A-A of Plate 16. The timber runners extended the full length of the item. The top membrane was buried at a 1-in. depth, and the bottom membrane was buried at a 5-in. depth. The width of buried membranes was 16 ft. Shoulders consisted of 2-ft-high mounds of sand positioned to provide a 10-ft-wide traffic lane. The surface of the east half of the item was sprayed with emulsified asphalt to produce a 1-in.-thick sand-asphalt wearing surface.

Materials

45. The concrete sand, aluminum grids, and T-17 membrane used in test section 2 were of the same type as those used in test section 1.

Mason sand

46. Classification data for this sand are shown in Plate 2. The sand was identical to the concrete sand except that it contained no coarse

sand larger than the No. 10 sieve size. Past experience with this sand showed that it would be more unstable than the concrete sand when subjected to rubber-tired traffic.

Polyester fabric

47. The fabric used was a 100 percent polyester nonwoven fabric called "Bidim" designed for civil engineering uses. Bidim is registered as a Monsanto trademark in the United States. Test supplies of the fabric, style C34, were purchased from the Monsanto Textiles Company, St. Louis, Missouri. Some physical properties of the fabric are:

Weight (oz per sq yd)	9
Thickness (mil)	109
Grab tensile strength (lb)	235
Grab elongation (percent)	57
Trapezoid tear strength (lb)	93
Mullen burst strength (psi)	422

SS-1 emulsified asphalt

48. Grade SS-1 emulsified asphalt is an anionic emulsion of asphalt cement and water, which contains a small amount of an emulsifying agent. It is a slow-setting-type emulsified asphalt with typical use in cold plant mix, road mix, slurry seal coat, tack coat, fog seal, dust layer, and mulch applications. Grade SS-1 was selected because it was locally available and also because it could be diluted with water if necessary for penetrating the compacted, wet test section sand (ASTM Designation: D 977-77, 1978a; or AASHTO Designation: M 140-70, 1974a).

Design

49. Test section 2 was designed based on the test results of test section 1. A design goal for the sand-grid items was 5000 passes of the highway-loaded M51 test vehicle with less than 3 in. of permanent depression at the grid surface. Excess sand above the grids was removed to eliminate the deep initial rutting that occurred in test section 1. With the excess cover sand removed, the sand-asphalt wearing surface could be constructed within the top inch of the grid cells.

50. Test items 1-4 were designed to allow additional study of

traffic performance versus grid cell size, grid thickness, grid sand quality, and surfacing requirements.

51. Test item 5 was designed to test an improved buried membrane concept. The membrane was nailed to timber side runners for better anchorage. Also, since results of test section 1 showed that wandering traffic caused increased lateral membrane movement, mounds of sand were placed on each shoulder to channelize traffic and help anchor the membrane along the sides. A thin sand and sand-asphalt surfacing was included in an attempt to improve vehicle traction and reduce the deep initial rutting that occurred with the thicker sand surfacings in test section 1.

Construction

52. A 150-ft section of the 12-in.-thick base layer of concrete sand from test section 1 was reshaped to form the base layer for test section 2.

Items 1-4 (square-type aluminum grids)

53. Grid installation was the same as in test section 1. The grids in the east half of the test section were filled with mason sand, and the grids in the west half were filled with concrete sand. A motor grader was used as shown in Photo 35. A vibratory drum roller compacted the sand into the grid cells (Photo 36). The motor grader bladed most of the remaining excess sand to the shoulders producing a smooth surface less than 1/2 in. above the grid surface. Some care was required in order to prevent the blade of the motor grader from damaging the grids. A final pass with the vibratory roller produced a smooth surface that exposed the tops of the grids in many locations.

54. In order to test a sand-asphalt surfacing technique that would be compatible with adverse wet weather conditions, the surfacing of the grid items was sprayed with water to allow the free-draining sand to hold its maximum amount of water. Some preliminary asphalt penetration tests were conducted using SS-1 emulsified at full strength and also diluted

with varying amounts of water. The results showed that the depth of penetration of the asphalt into the wet sand layer could be increased by diluting the SS-1 with water. Also, it was found that if less penetration was desired, a light application of asphalt could be applied, allowed to break, and then followed by a second application of asphalt. However, it was found that a 1-in. penetration of the asphalt into the sand grids would be achieved by simply spraying approximately 1 gal per sq yd of full-strength SS-1 (not heated) onto the wet sand-grid surface. Photo 37 shows the surface of item 1 immediately after approximately 0.75 gal per sq yd of SS-1 was sprayed. (The tops of the grids can still be seen in several locations.) Photo 38 shows the polyester fabric in place on item 1, and Photo 39 shows the fabric being sprayed with SS-1 at approximately 0.5 gal per sq yd. Photo 40 shows the asphalt-saturated fabric surfacing for item 1 and also a portion of the remaining grid items after they were sprayed with full-strength SS-1 at an application rate of approximately 1 gal per sq yd. Photo 41 shows the completed grid items after an application of blotter sand had been applied.

Item 5 (T-17 membrane)

55. The base layer of sand was leveled and compacted with a small vibratory plate compactor at 5 in. below final grade. Next, a 16- by 30-ft section of T-17 membrane was placed on the sand layer and nailed to two 4- by 4-in. side runners (Photo 42). A 4-in. layer of wet sand was placed over the membrane, leveled, and compacted; then a second section of membrane was installed and nailed to the side runners. The 1-in. sand surfacing and mounded sand shoulders were then completed. The east half of the item was sprayed with asphalt and blotted with sand. Photo 43 shows the completed item prior to traffic.

Traffic Tests

Application of traffic

56. Test traffic was applied during August, September, and October of 1978. Traffic was applied using the same test vehicle as was used for test section 1. The test vehicle wheel load was the same as in test

section 1 (Figure 4) for the first 5,000 passes of traffic. The rear tandem axle load was then increased by 10,000 lb (single-wheel load increased from 4,140 to 5,390 lb), and an additional 1,500 passes of traffic were applied to some items. The tire pressure was 70 psi during all traffic tests. The test section was trafficked as a one-lane road.

Tests and observations

57. Visual observations, photographs, and cross-section level readings were recorded at intervals throughout the traffic test period. After 3500 passes of traffic, item 5 was dismantled to determine the condition and position of the membranes. After 5000 passes of traffic, trenches were excavated across items 1-4 to obtain data on grid performance and subgrade rutting. The performance of the test items under traffic and the data obtained are presented in the following paragraphs.

Item 1 (6-in.-square grids, 8-in. thick, with asphalt-fabric surfacing)

58. Performance of this item was outstanding. Photo 44 shows the item after 100 passes of traffic. Rut depths were less than 1 in. in both wheel paths. Photo 45 shows the item after 5000 passes. The surfacing membrane had pulled in several inches from the sides, but the average rut depths were only 4.1 and 3.8 in. in the east and west wheel paths, respectively. Permanent surface depression in each wheel path was less than 2 in. Photo 46 shows the trench cut across the item after 5000 passes. Subgrade ruts were 0.5 in. in each wheel path. Notice how the bent tops of the grids came through the asphalt-fabric membrane (Photo 46). The sand-grid thickness had been reduced to approximately 7 in. in each wheel path. Typical cross-section data are shown in Plate 17.

59. The test trench was filled with crushed limestone; the test vehicle load was increased by 10,000 lb; and traffic was resumed. A total of 1,500 passes of traffic was applied at the new loading. At the conclusion of traffic, average rut depths were 4.7 and 4.5 in. in the east and west wheel paths, respectively. The permanent surface depression was 2.5 and 2.1 in. in the east and west wheel paths, respectively. Photo 47 shows the item still in good condition after 6,500 passes of traffic.

Item 2 (6-in.-square
grids, 8 in. thick)

60. Performance of this item was slightly better than that of item 1. Photo 48 shows the item after 100 passes of traffic. Rut depths were approximately 0.5 in. in both wheel paths. The blotter sand in the east wheel path was partially removed by this time exposing the tops of the grids. The blotter sand removal was caused by the truck tires picking up asphalt from the east wheel path of item 5 and then rolling over the grid items with slightly tacky tires. After 5000 passes (Photo 49), the average rut depths were 3.6 and 3.2 in. in the east and west wheel paths, respectively. Permanent surface depression in each wheel path was less than 2 in. (The tracks visible outside the east wheel path were caused by two passes of an M50 tank, which were applied to the test section after 1000 passes of truck traffic.) A trench cut across the item after 5000 passes revealed that the sub-grade ruts were 0.7 and 0.5 in. in the east and west wheel paths, respectively. The sand-grid thickness had been reduced to approximately 7 in. in each wheel path. Typical cross-section data are shown in Plate 18.

61. Photo 50 shows the item after an additional 1500 passes of traffic were applied at the increased truck load. Average rut depths were 4.4 and 3.4 in. in the east and west wheel paths, respectively. The permanent surface depression was 2.4 and 2.2 in. in the east and west wheel paths, respectively. The sand-grid layer was in excellent condition and could have handled a substantial amount of additional traffic.

Item 3 (8-in.-square
grids, 8 in. thick)

62. Traffic on this item demonstrated that performance decreased as grid cell size increased and that grid-sand type was critical in larger cell grids. Photo 51 shows the item after 100 passes of traffic. Rut depths averaged 1.3 and 1.1 in. in the east and west wheel paths, respectively. After 3000 passes (Photo 52), the average rut depths were 8.4 and 4.5 in. in the east and west wheel paths, respectively. The permanent surface depression in the east wheel path was 3.4 in. and the

grids had broken up along both edges of the wheel path. Pieces of grid along with clean sand from the grid cells were visible in the wheel path. The permanent surface depression in the west wheel path was 1.6 in., and the sand-grid layer was still in good condition.

63. After 5000 passes (Photo 53), the average rut depths were 9.3 and 4.9 in. in the east and west wheel paths, respectively. The permanent surface depression in the west wheel path had increased to 2.4 in., and the sand-grid layer was in fair condition. A trench cut across the item (Photo 54) revealed subgrade rutting of 1.7 and 0.8 in. in the east and west wheel paths, respectively. The minimum grid thickness was 3.8 and 6.4 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 19.

64. The truck load was increased, and an additional 1500 passes of traffic were applied. During the first 500 passes at the increased loading, loose material from the sides of the east wheel path fell into the wheel path and caused a 1.2-in. reduction in the rut depth. However, at the conclusion of traffic, the rut depth and surface depression measurements were 10.0 and 6.0 in., respectively, for the east wheel path. For the west wheel path, the rut depth and surface depression measurements averaged 5.9 and 2.5 in., respectively.

Item 4 (6-in.-square
grids, 6 in. thick)

65. Traffic on this item showed that grid thickness and grid-sand type are related to performance. After 100 passes (Photo 55), rut depths averaged 0.6 and 0.8 in. in the east and west wheel paths, respectively. After 3000 passes (Photo 56), rut depths averaged 5.9 and 4.1 in. in the east and west wheel paths, respectively. The permanent surface depression in the east wheel path was 2.4 in. Pieces of grid were emerging from the edges of the wheel path. The permanent surface depression in the west wheel path was 2.0 in., and the sand-grid layer was still in good condition.

66. After 5000 passes (Photo 57), the average rut depths were 6.8 and 4.4 in. in the east and west wheel paths, respectively. The permanent surface depression was 3.3 and 2.7 in. in the east and west wheel

paths, respectively. A trench cut across the item (Photo 58) revealed subgrade rutting of 2.5 and 1.4 in. in the east and west wheel paths, respectively. The minimum sand-grid thickness was 3.7 and 4.1 in. in the east and west wheel paths, respectively. Typical cross-section data are shown in Plate 20.

67. Additional traffic at the heavier truck weight caused rapid rut depth increases in the east wheel path. After 1500 passes of traffic at the increased weight, the average rut depth in the east wheel path was 11.0 in., and the permanent surface depression was 5.8 in. The west wheel path rut depth had only increased to 5.7 in. with a permanent surface depression averaging 3.4 in.

Item 5 (T-17 membrane)

68. Performance of this membrane item was a significant improvement over the two membrane items tested in test section 1. Photo 59 shows the item after 100 passes. The rut depths averaged approximately 5.5 in. in each wheel path. Photo 60 shows the item after 3500 passes of traffic. Spot failures had developed in the top layer of membrane in each wheel path. The membrane failures were a result of abrasive wear from the sand surfacing and truck tires. The average rut depths had increased very slowly and were 7.4 and 7.2 in. in the east and west wheel paths, respectively. Photo 61 shows a sectional view of the item after the surfacing sand and top membrane were removed at 3500 passes. Average rut depth measurements on the bottom membrane were 2.2 and 2.5 in. for the east and west wheel paths, respectively. The timber runners along each side of the item were successful in preventing the membranes from pulling in toward the wheel paths. Typical cross-section data are shown in Plate 21.

Summary of Test Results

69. Plates 22-26 and Tables 1 and 2 show the summary of test results for test section 2. The data presented were developed as described in paragraphs 42 and 43. The decreases in rut depth and/or permanent surface depression at increased traffic passes that resulted

in items 2-5 (Plates 23-26) were caused by traffic wander. Traffic wander increased slightly as the number of traffic passes increased. The increased wander caused some of the upheaval along the wheel path edges to fall into the wheel path. This caused a temporary reduction in the rut depth and/or permanent surface depression measurement. A significant reduction in the rut depth resulted in the already deeply rutted east wheel path of item 3 (Plate 24) after the truck weight was increased by 10,000 lb. The heavier truck apparently caused some of the upheaval to fall into the east wheel path of item 3.

PART IV: ANALYSIS, CONCLUSIONS, AND RECOMMENDATIONS

Analysis

Optimum sand-grid properties

70. Plate 27 shows a plot of grid size versus permanent surface depression at the grid surface for all aluminum-grid items tested. Based on the test traffic performance of these items, performance was generally good until the permanent depression at the grid surface was approximately 3 in. At this point, the grids would begin to fall apart along the edges of the wheel path. Therefore, a 3-in. permanent depression at the grid surface was chosen as the failure criteria for the sand-grid combinations tested. Plate 27 shows that grid performance is not based solely on grid size. Other important properties relating to performance are grid thickness, grid-sand type, and the type of surfacing used. Based on the tests conducted to date and on the information contained in Plate 27, a flow diagram (Plate 28) was developed showing the relationship of sand-grid properties and the test results of the first 5000 passes of traffic. Based on the information shown in Plate 28, the optimum sand grid has a 6-in. cell size that is 8 in. thick and filled with either a uniform or better quality type of sand. The sand must be compacted in the grid cells. The sand-grid layer must also have an adequate wearing surface. A 1-in. layer of sand asphalt within the top of the grids provided an adequate wearing surface for the test traffic applied to test section 2.

Predicted passes versus payload

71. Test items 1 and 2 of test section 2 contained optimum sand-grid properties. The passes versus permanent surface depression plots in Plates 22 and 23 for these items indicated that a 3-in. permanent surface depression (failure criteria) would have developed in the east wheel path (mason sand) at approximately 8000 passes if traffic were continued at the increased loading. The west wheel path (concrete sand) would have developed a 3-in. permanent surface depression at approximately 9000 passes.

72. In order to compare the test traffic with that of the XM 878 truck-XM 872 semitrailer combination, load equivalency factors were used. Load equivalency factors are numerical factors that express the relationship between a given axle load and an equivalent number of repetitions of 18-kip single-axle loads. They are useful in pavement design procedures for converting projected mixed traffic to repetitions of equivalent 18-kip single-axle loads. Load equivalency factors used in flexible pavement design procedures by the American Association of State Highway and Transportation Officials (AASHTO), the Asphalt Institute, and the U. S. Army Corps of Engineers are shown in Plate 29. Disagreement in the load equivalency factors between the three agencies is significant, particularly at the high tandem-axle loads. Since the Asphalt Institute (1969) factors compromise those of AASHTO and the Corps, they were selected for use in this study. The Asphalt Institute load equivalency factors state that insofar as general performance of pavement structure and subgrade soil is concerned, a 32,000-lb tandem-axle load is basically equivalent to an 18,000-lb single-axle load. This relationship also holds for other loads so that a tandem-axle load when multiplied by 0.57 gives the equivalent single-axle load.

73. The Asphalt Institute load equivalency factors were used to convert the test traffic into equivalent 18-kip single-axle loads. The projected 8,000 and 9,000 passes of test traffic converted to 25,040 and 31,120 equivalent 18-kip single-axle loads for the east and west wheel paths, respectively. Next, the load equivalency factors were used to develop the load equivalency information shown in Plate 30 for the XM 878 truck-XM 872 semitrailer combination. The triaxle wheel arrangement on the semitrailer was treated as 1.5 tandem axles when using the load equivalency factors. Based on the projected test traffic (in equivalent 18-kip single-axle loads) and on the information in Plate 30, predicted performance for container operations over grid-stabilized beach sand was developed (Plate 31).

74. An example of how the information in Plate 31 could be used follows. Assume an unstable beach sand having a uniform grain size similar to that of mason sand. The sand is stabilized using aluminum

grids that have a 6-in. cell size and an 8-in. thickness. A sand-asphalt wearing surface is formed in the top inch of the grid cells. Assume containerships loaded with containers weighing up to 50 kips each. Then, if the maximum container payload hauled on a truck is limited to 50 kips, Plate 31 shows that the grid-stabilized sand will handle approximately 4900 passes of loaded container trucks before a 3-in. permanent depression develops at the grid surface. If, on the other hand, all trucks were loaded to the maximum payload of 67.2 kips, only 1400 passes could be applied.

Conclusions

75. The following conclusions regarding sand trafficability enhancement using sand-filled confinement grids are based on the findings of tests reported herein:

- a. Grid material type, cell size, thickness, sand type, and surfacing are all related to traffic performance.
- b. The sand-filled grids must have an adequate surfacing in order to perform properly. A sand surfacing over the grids is not adequate. A sand-asphalt surfacing within the top inch of the grid cells is adequate. The sand-asphalt surfacing can easily be constructed by spraying a suitable liquid asphalt (such as grade RC 250 or SS-1) over the compacted surface of the sand-filled grids. The sand can be wet, but it must be in a free-drained condition.
- c. The asphalt-fabric membrane over the sand-asphalt surfacing offered no improvement in performance.
- d. The grid material must be strong enough to withstand the sand filling and compaction processes and also not weaken when wet. The paper grids tested were not acceptable because they lost strength when wet. All the aluminum grids tested were adequate from a material standpoint.
- e. As the grid cell size increases, the type of sand used to fill the grids affects performance. For a 6-in. cell, 8 in. thick, concrete sand offered only slightly better performance than mason sand. However, with an 8-in. cell, 8 in. thick, concrete sand significantly outperformed the mason sand.

- f. As the grid thickness decreases, the type of sand used to fill the grids also becomes important. For a 6-in. cell, 6 in. thick, concrete sand offered better performance than the mason sand.
- g. Aluminum grids with a 6-in. cell size, 8 in. thick, filled with either a uniform or well-graded compacted beach sand, and surfaced with a spray application of suitable liquid asphalt should adequately handle tractor-trailer container operations during over-the-shore operations.

76. The following conclusions regarding sand trafficability enhancement using membrane reinforcement layers are based on the findings of tests reported herein:

- a. Two layers of T-17 membrane buried in unstable sand at 1- and 5-in. depths, respectively, and anchored from side pull-in by nailing to timber side runners can increase the trafficability of a loaded 5-ton truck from 10 passes to more than 3500 passes before an 11-in. rut develops.
- b. Advantages in using membrane reinforcement to stabilize sands include construction expediency, low labor skill requirements, and low hauled-in tonnage requirements.
- c. Disadvantages of the membrane concepts tested to date are substantial initial rutting and potential loss of traction.

Recommendations

77. It is recommended that:

- a. Tests be conducted using hexagonal-shaped aluminum grids. Test supplies of unexpanded hexagonal grids have been purchased under contract. Optimum hexagonal grid size could be determined, and information regarding construction requirements could be developed. The material, manpower, construction equipment, shipping weights and volumes, and construction time estimates could be established. This information is necessary for comparing the sand-grid concept with other alternatives, such as landing mat, for potential use in over-the-shore operations.
- b. Tests be continued using improved expedient membrane concepts. Construction expediency and minimum material requirements make the membrane concept attractive.

- c. Potential traction problems, particularly on slopes, and the wheel slip damage to enhancement systems be studied. The XM 878 truck tractor may have problems towing three unpowered axles of 56,250 lb plus an 8,840-lb front axle with only one powered axle of 18,750 lb. The XM 915, 6 x 4, truck tractor would probably be a much better performer with the XM 872 semitrailer if traction problems are severe.
- d. The results of the sand-grid tests reported herein also be considered applicable for building bridge approach roads across sand riverbanks.

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Table 1

Sand Grid Test Items

Summary of Traffic Test Data

Test Item	Grid* Size in.	Grid** Sand Type	Wheel Path	Surfacing Type	Thickness in.	Traffic Passes	Traffic Wander in.	Avg. Min. Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.†
Control Item (No Grids)											
8	No Grids	--	West East	Sand Sand-asphalt	-- 0.75-1.0	10 10	-- --	-- --	Surface Surface	12.5 12.7	6.4 6.7
Test Section 1 (Hexcel Paper Grids)											
5	8x6	Concrete	West East	Sand Sand-asphalt over sand††	1.0 2.0	75 75	-- --	0 0	Surface Surface	9.2 9.6	4.1 4.3
6	12x6	Concrete	West East	Sand Sand-asphalt over sand††	1.4 1.6	10 10	-- --	0 0	Surface Surface	10.7 11.0	5.3 5.8
Test Section 1 (Aluminum Grids)											
1	4x4x6	Concrete	West	Sand	1.5	4850	18	4.2	Surface Top of grids Subgrade surf.	9.1 3.5 1.7	3.8 3.5 1.7
2	6x6x6	Concrete	East	Sand-asphalt over sand††	1.8	4850	18	5.5	Surface Top of grids Subgrade surf.	9.2 1.6 1.5	3.6 1.6 1.1
			West	Sand	2.2	2500	18	3.8	Surface Top of grids Subgrade surf.	10.4 3.4 1.7	4.9 3.4 1.2
			East	Sand-asphalt over sand††	3.5	2000	18	3.3	Surface Top of grids Subgrade surf.	11.8 4.1 2.0	5.2 4.1 1.4

(Continued)

* Last number denotes initial grid thickness.

** The subgrade for all test items was concrete sand; however, the grid cells were filled with either concrete or mason sand.

† Average maximum value listed from three cross-section locations.

†† Thickness of the sand-asphalt was 0.75 to 1.0 in.

(Sheet 1 of 3)

Table 1 (Continued)

Test Item	Grid Size in.	Grid Sand Type	Wheel Path	Surfacing		Traffic Passes	Traffic Wander in.	Avg. Min. Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
				Type	Thickness in.						
3	8x8x6	Concrete	West	Sand	1.5	600	18	3.1	Surface	10.9	4.5
									Top of grids	4.7	4.7
									Subgrade surf.	1.8	1.8
									Surface	10.6	4.9
4	6x6x8	Concrete	East	Sand-asphalt over sand††	1.5	600	18	1.5	Top of grids	5.0	5.0
									Subgrade surf.	1.0	0.5
			West	Sand	1.6	4850	18	5.9	Surface	11.0	4.6
									Top of grids	5.0	3.4
1	6x6x8	Concrete	East	Sand-asphalt over sand††	1.6	4850	18	5.8	Subgrade surf.	1.3	1.3
									Surface	10.1	4.8
									Top of grids	4.2	3.2
									Subgrade surf.	1.5	1.0
Test Section 2 (Aluminum Grids)											
1	6x6x8	Concrete	West	Asphalt-fabric membrane over sand-asphalt	1.0-1.25	5000	3	6.9	Surface	3.8	1.6
									Top of grids	1.6	1.6
									Subgrade surf.	0.5	0.5
									Surface	4.5	2.1
2	6x6x8	Mason	East	Asphalt-fabric membrane over sand-asphalt	1.0-1.25	5000	3	6.7	Subgrade surf.	--	1.0
									Surface	4.1	1.8
									Top of grids	1.8	1.8
									Subgrade surf.	0.5	0.5
2	6x6x8	Concrete	West	Sand-asphalt	0.75-1.0	5000	3	6.7	Surface	4.7	2.5
									Subgrade surf.	--	1.2
									Surface	3.2	1.7
									Top of grids	1.7	1.7
2	6x6x8	Concrete	West	Sand-asphalt	0.75-1.0	5000	3	6.8	Subgrade surf.	0.5	0.5
									Surface	3.4	2.2
									Top of grids	1.7	1.7
									Subgrade surf.	--	1.0

†† Thickness of the sand-asphalt was 0.75 to 1.0 in.

* The load on the traffic test vehicle was increased from 20 to 30 kips at 5000 passes.

(Sheet 2 of 3)

Table 1 (Concluded)

Test Item	Grid Size in.	Grid Sand Type	Wheel Path	Surfacing		Traffic Passes	Traffic Wander in.	Avg. Min. Grid Thickness in.	Location	Rut Depth in.	Permanent Depression in.
				Type	Thickness in.						
Test Section 2 (Aluminum Grids) (Continued)											
2	6×6×8	Mason	East	Sand-asphalt	0.75-1.0	5000	3	6.9	Surface	3.6	1.8
									Top of grids	2.1	1.8
									Subgrade surf.	0.7	0.7
									Surface	4.4	2.4
3	8×8×8	Concrete	West	Sand-asphalt	0.75-1.0	5000	5	6.4	Subgrade surf.	--	1.3
									Surface	4.9	2.4
									Top of grids	2.5	2.4
									Subgrade surf.	0.8	0.8
									Surface	5.9	2.5
									Subgrade surf.	--	--
4	6×6×6	Mason	East	Sand-asphalt	0.75-1.0	5000	5	3.8	Surface	9.3	5.0
									Top of grids	8.0	5.0
									Subgrade surf.	1.7	0.8
									Surface	10.0	6.0
									Subgrade surf.	--	--
									Surface	4.4	2.7
		Concrete	West	Sand-asphalt	0.75-1.0	5000	5	4.1	Top of grids	2.7	2.7
									Subgrade surf.	1.4	0.8
									Surface	5.7	3.4
									Subgrade surf.	--	1.5
		Mason	East	Sand-asphalt	0.75-1.0	5000	5	3.7	Surface	6.8	3.3
									Top of grids	6.7	3.3
									Subgrade surf.	2.5	1.0
									Surface	11.0	5.8
									Subgrade surf.	--	1.2

* The load on the traffic test vehicle was increased from 20 to 30 kips at 5000 passes.

(Sheet 3 of 3)

Table 2

Membrane Test Items

Summary of Traffic Test Data

Section	Test Item	Membrane			Wheel Path	Surfacing		Traffic Passes	Traffic Winder in.	Location	Rut Depth in.	Permanent Depression in.*
		Type	No. Layers	Location Depth in.		Type	Thickness in.					
1	7	T-17	2	3 & 6	West	Sand	3	1000	24	Surface Top memb. Bottom memb.	10.1 -- 5.8	4.7 2.0 2.3
					East	Sand-asphalt over sand**	3	1000	24	Surface Top memb. Bottom memb.	9.3 6.8 2.5	4.1 3.0 1.3
1	6A	T-17	1	4	Both	Sand	4	900	24	Surface Memb.	11.1 8.0	5.0 4.0
2	5	T-17	2	1 & 5	West	Sand	1	3500	3	Surface Top memb. Bottom memb.	7.2 8.2 2.5	3.5 3.5 1.8
					East	Sand-asphalt	1	3500	3	Surface Top memb. Bottom memb.	7.4 8.4 2.2	4.2 4.2 1.5

* Average maximum value measured from three cross-section locations.

** Thickness of the sand-asphalt was 0.75 to 1.0 in.

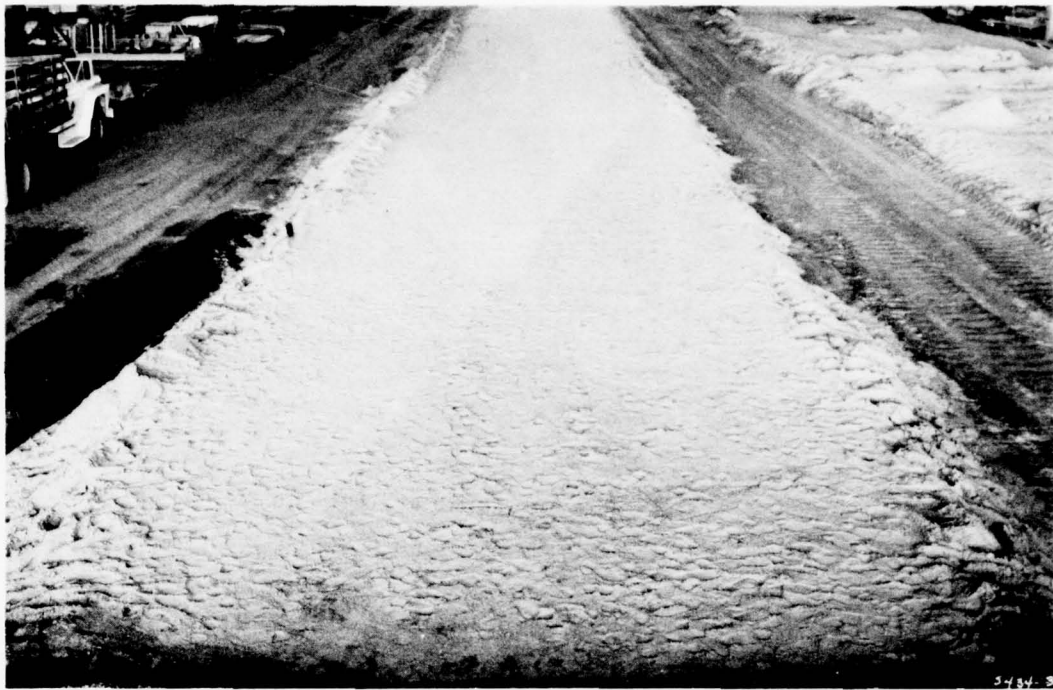


Photo 1. Base layer of sand on which test items were constructed, test section 1

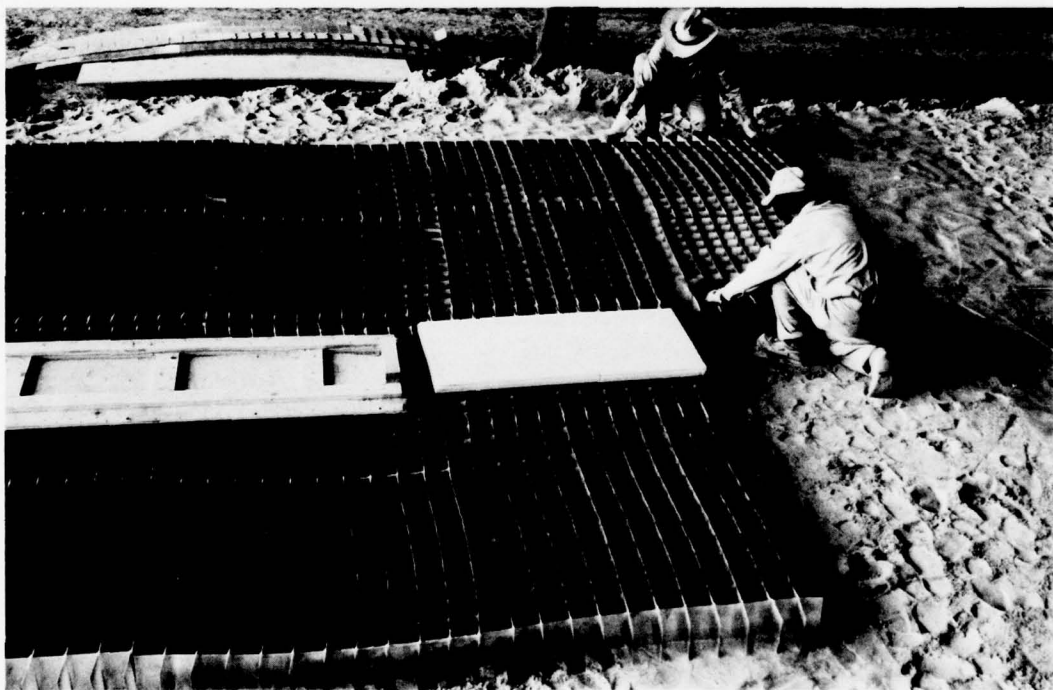


Photo 2. Installing grids in item 1, test section 1

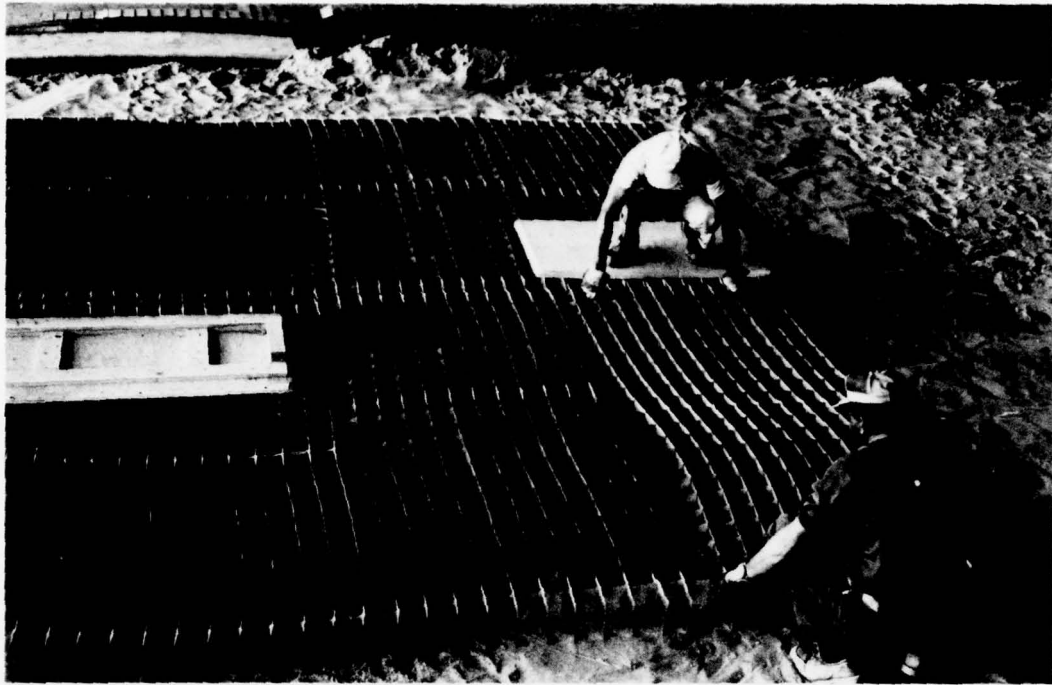


Photo 3. Installing grids with aid of Styrofoam board,
test section 1

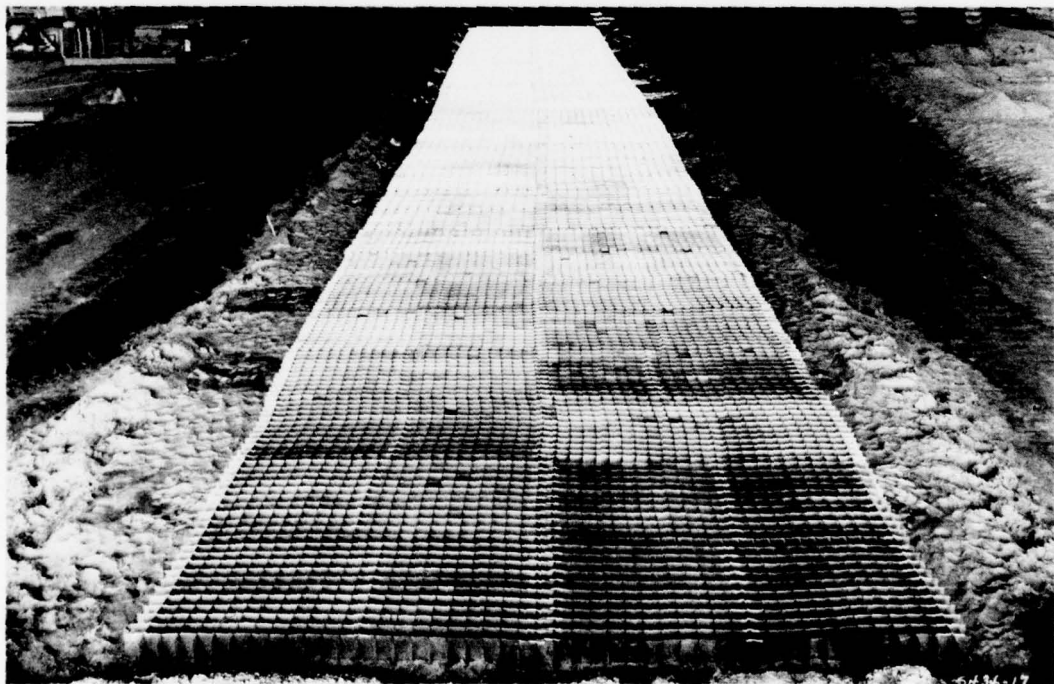


Photo 4. Overall view of installed grids,
test section 1



Photo 5. End dumping sand on grids,
test section 1

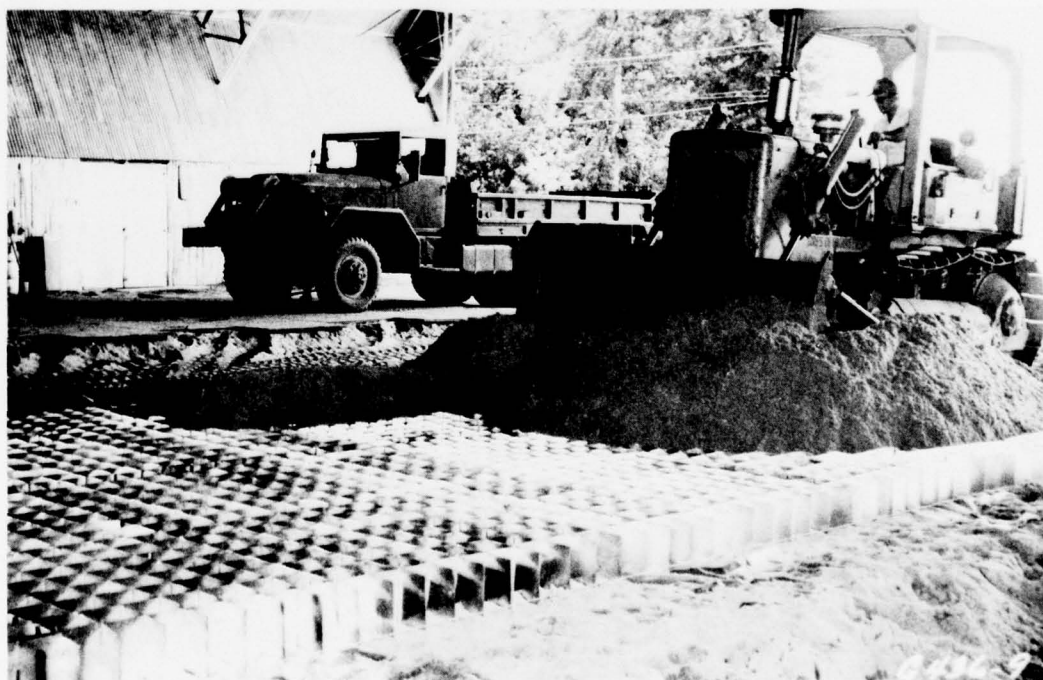


Photo 6. Tractor pushing sand forward into grid cells,
test section 1

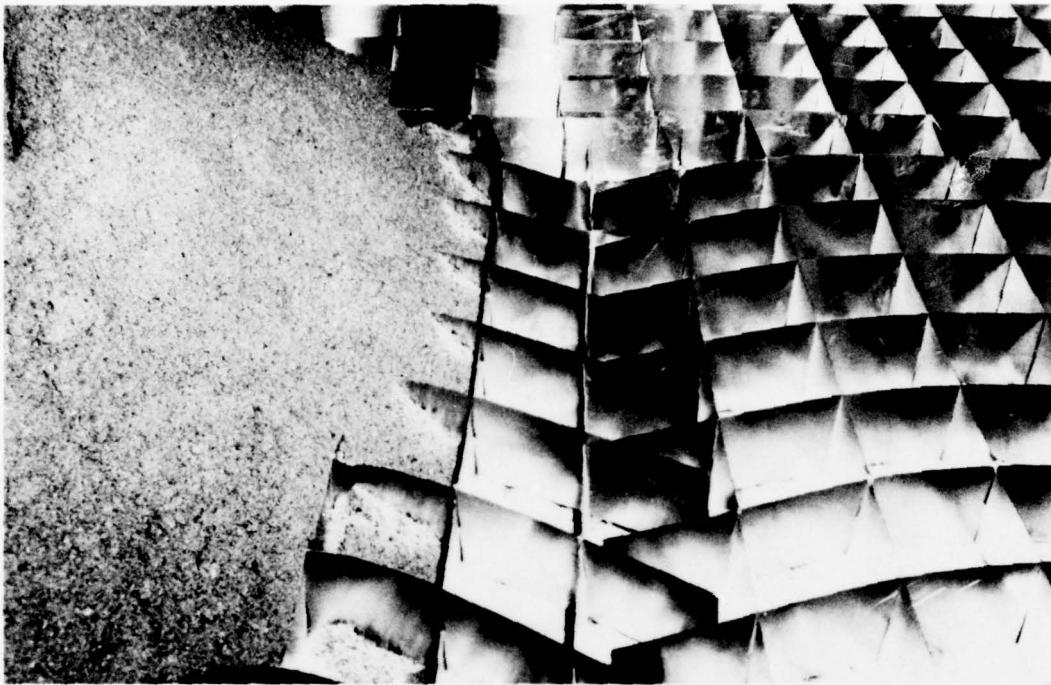


Photo 7. Grid movement caused by tractor pushing sand into grid cells, test section 1

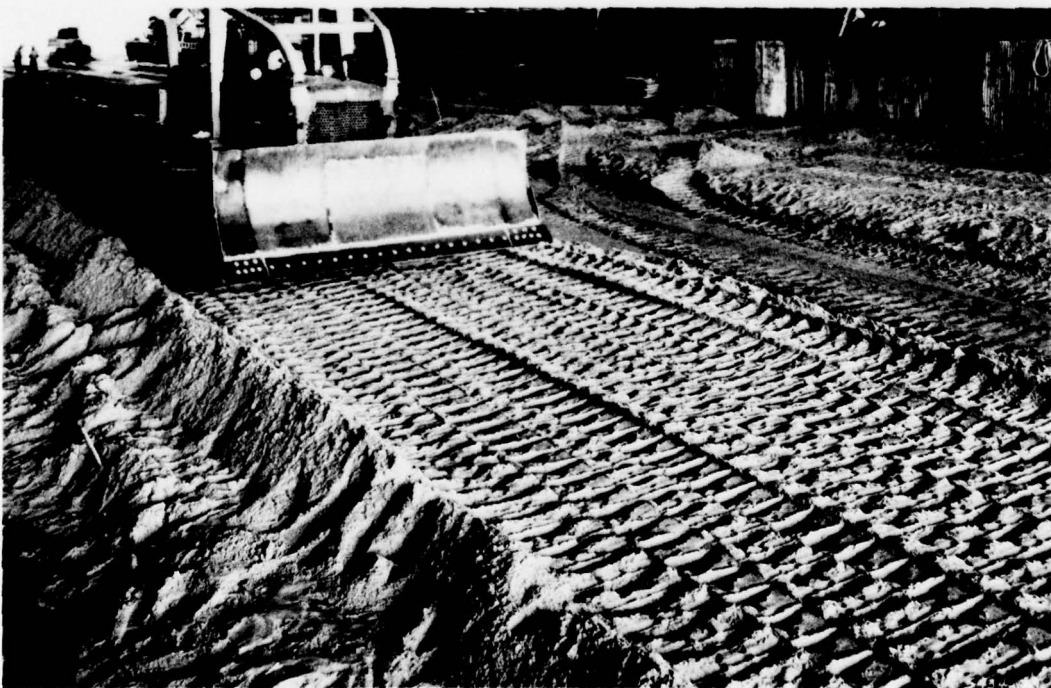


Photo 8. Tractor smoothing and compacting sand-grid layer, test section 1



Photo 9. Compacting sand-grid layer using towed-type rubber-tired roller, test section 1



Photo 10. Closeup view of 8-in. Hexcel paper grids, item 5, test section 1



Photo 11. Closeup view of 12-in. Hexcel paper grids,
item 6, test section 1



Photo 12. Leveling and compacting base layer of sand, item 7,
test section 1



Photo 13. Bottom layer of T-17 membrane installed,
item 7, test section 1



Photo 14. Spraying RC 800 liquid asphalt on sand surfacing,
east half of test section, test section 1



Photo 15. Overall view showing asphalt penetration after 24 hr,
test section 1



Photo 16. Military 5-ton, M51, test vehicle,
test section 1



Photo 17. Item 1 after 500 passes of test vehicle,
test section 1



Photo 18. Item 1 after 4850 passes, test section 1



Photo 19. Sand-grid layer after 4850 passes, item 1,
test section 1



Photo 20. Item 2 after 500 passes, test section 1

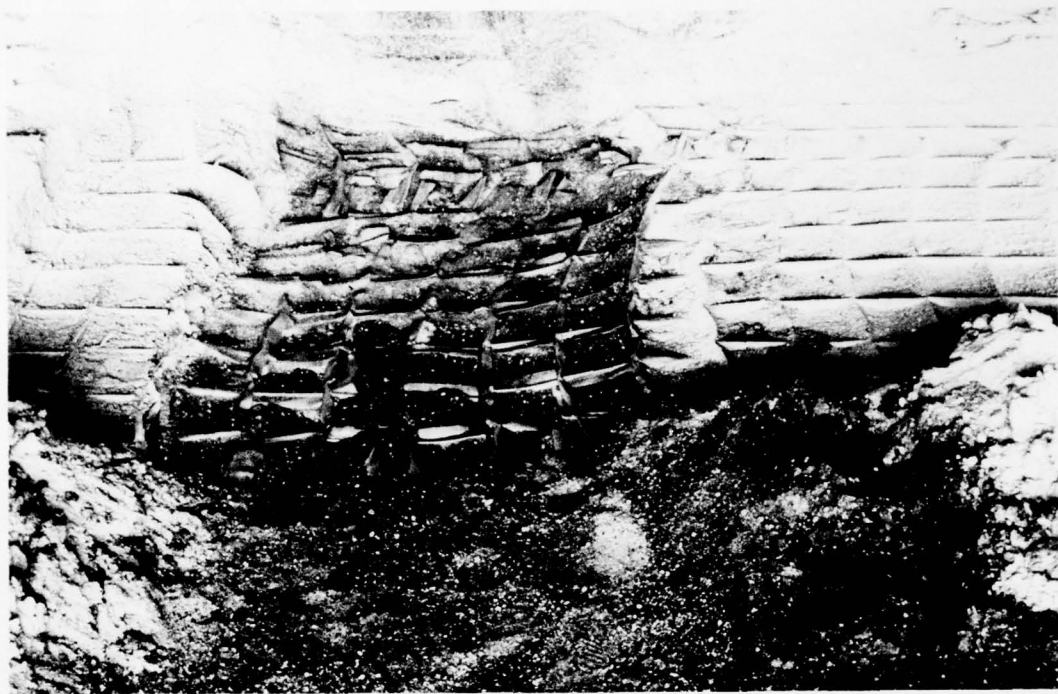


Photo 21. East wheel path grid surface after 2000 passes,
item 2, test section 1

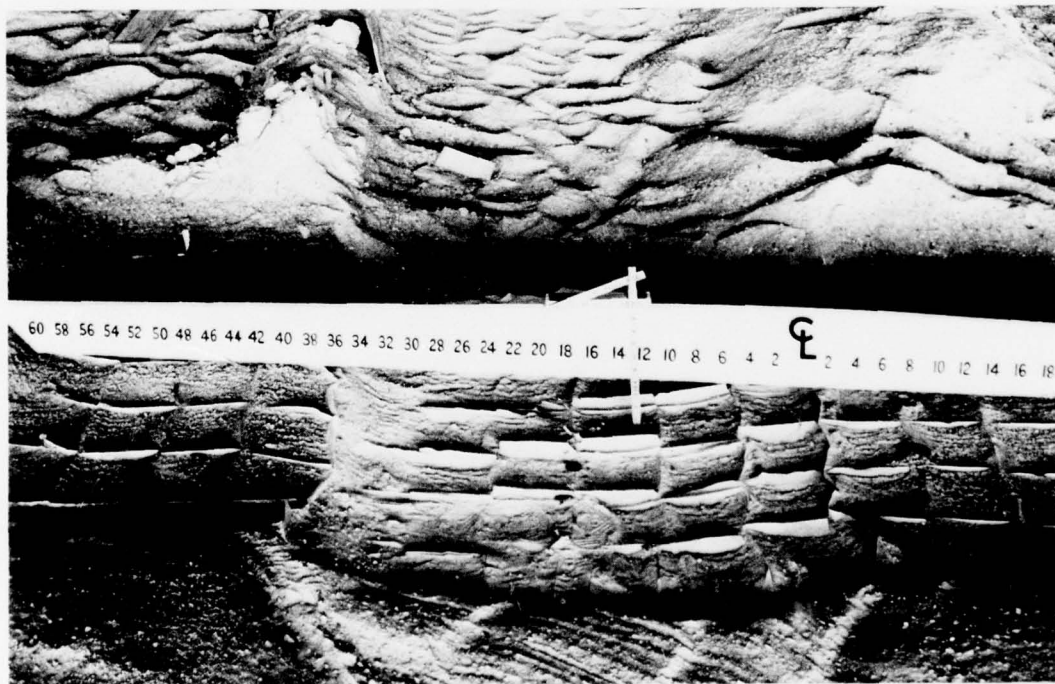


Photo 22. West wheel path grid surface after 2500 passes,
item 2, test section 1



Photo 23. Item 4 after 500 passes, test section 1

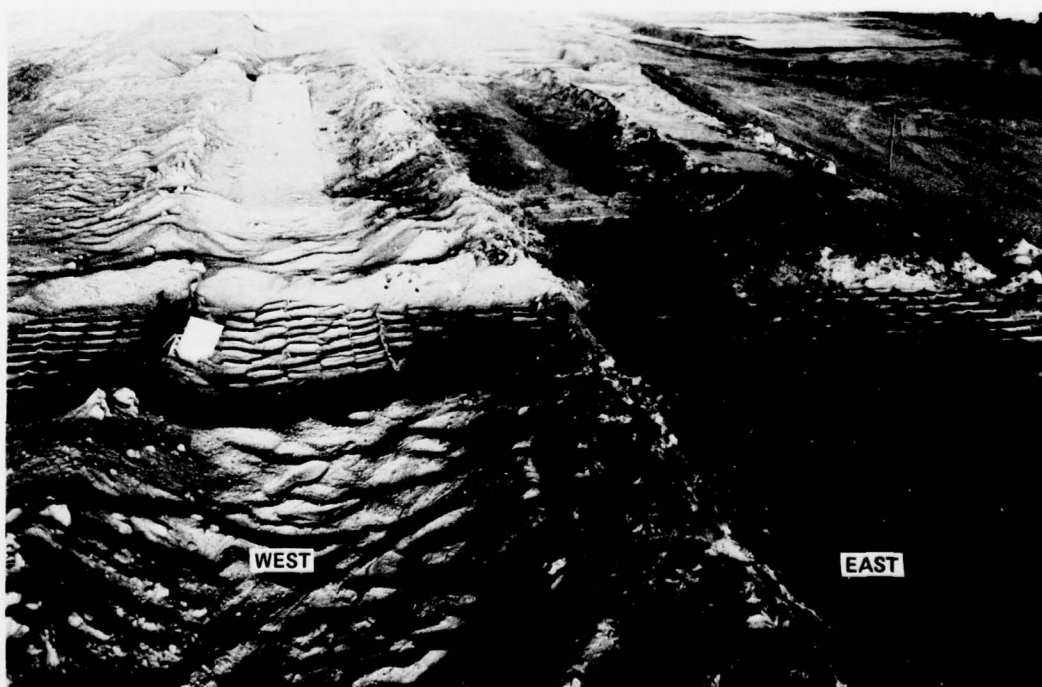


Photo 24. Grid surface after 4850 passes, item 4, test section 1

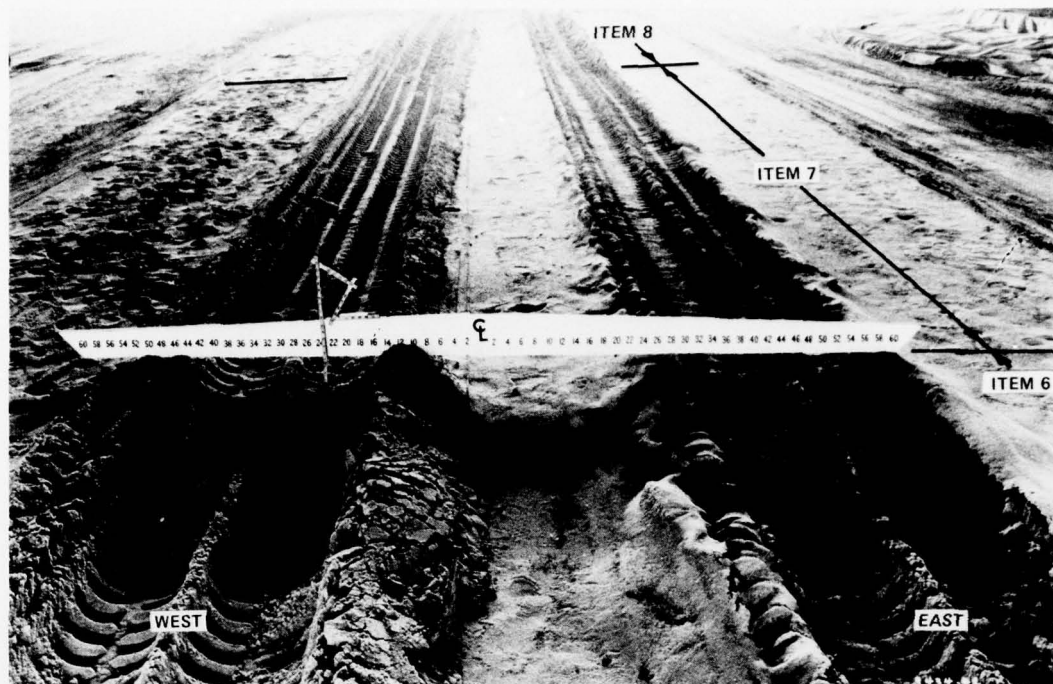


Photo 25. Items 6-8 after five passes, test section 1

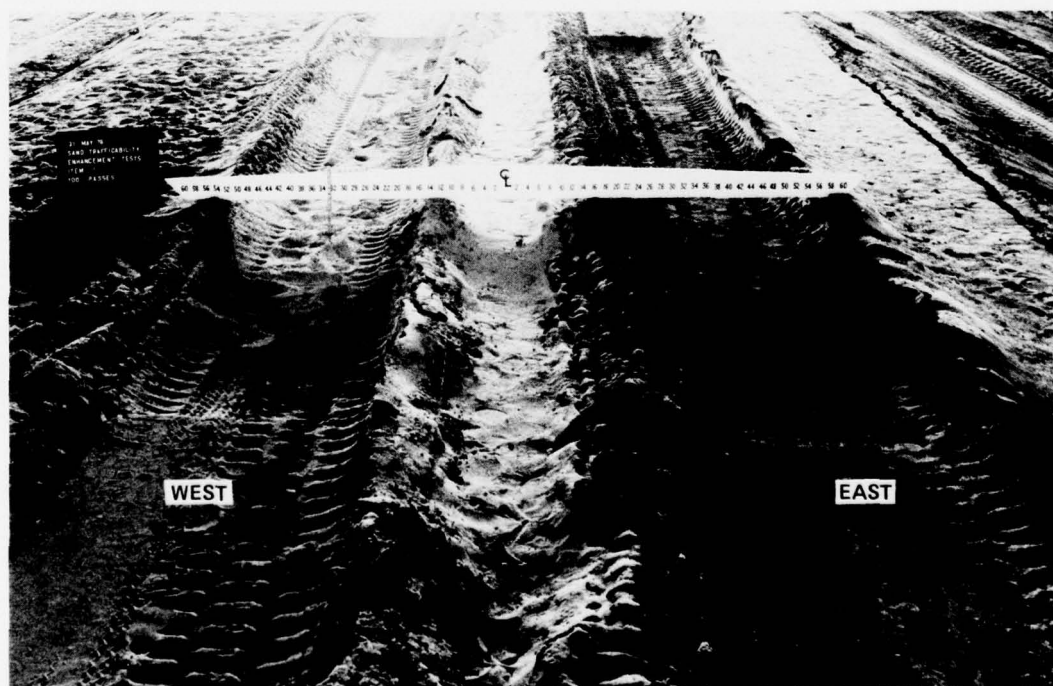


Photo 26. Item 7 after 100 passes, test section 1



Photo 27. Item 7 after 1000 passes, test section 1

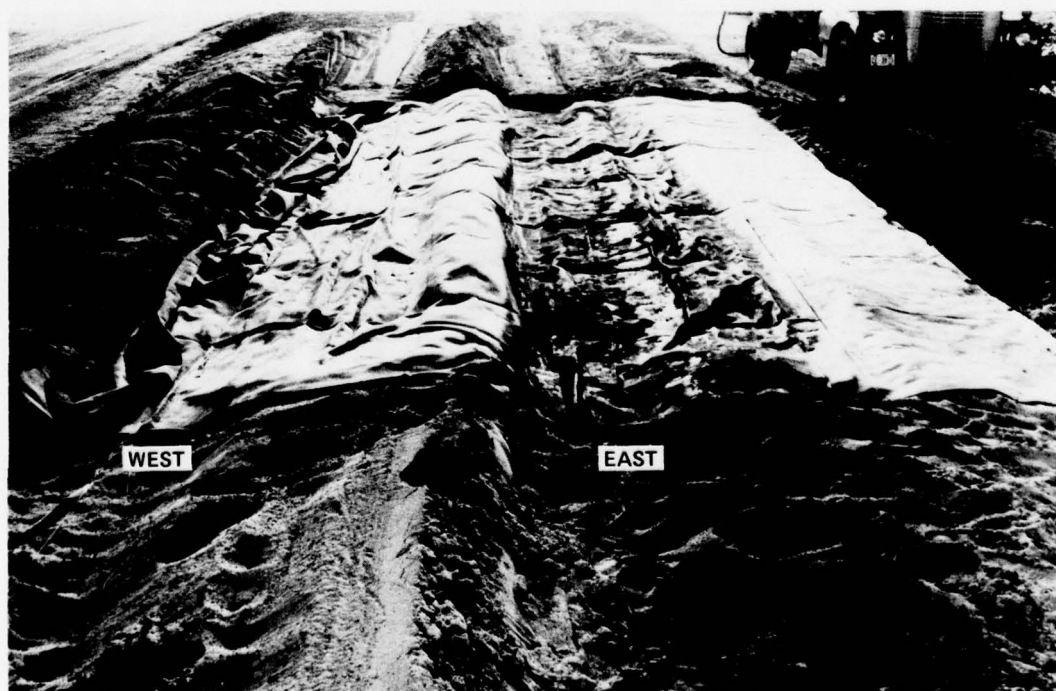


Photo 28. Top layer of membrane after 1000 passes,
item 7, test section 1

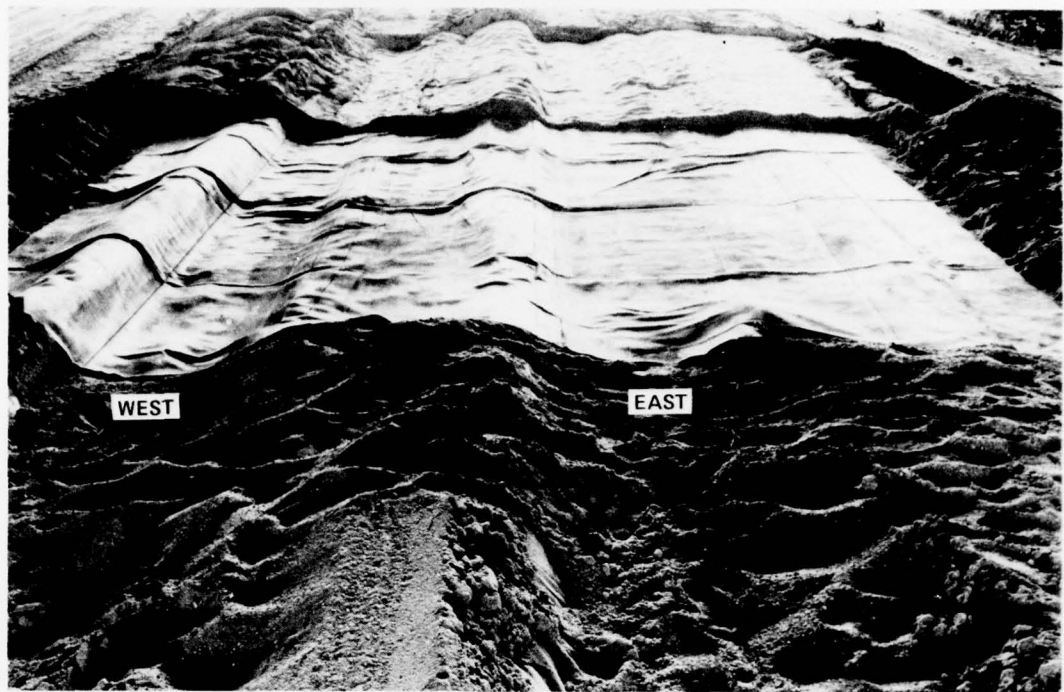


Photo 29. Bottom membrane and cover sand after 1000 passes,
item 7, test section 1



Photo 30. Items 7 and 8 after 10 passes, test section 1

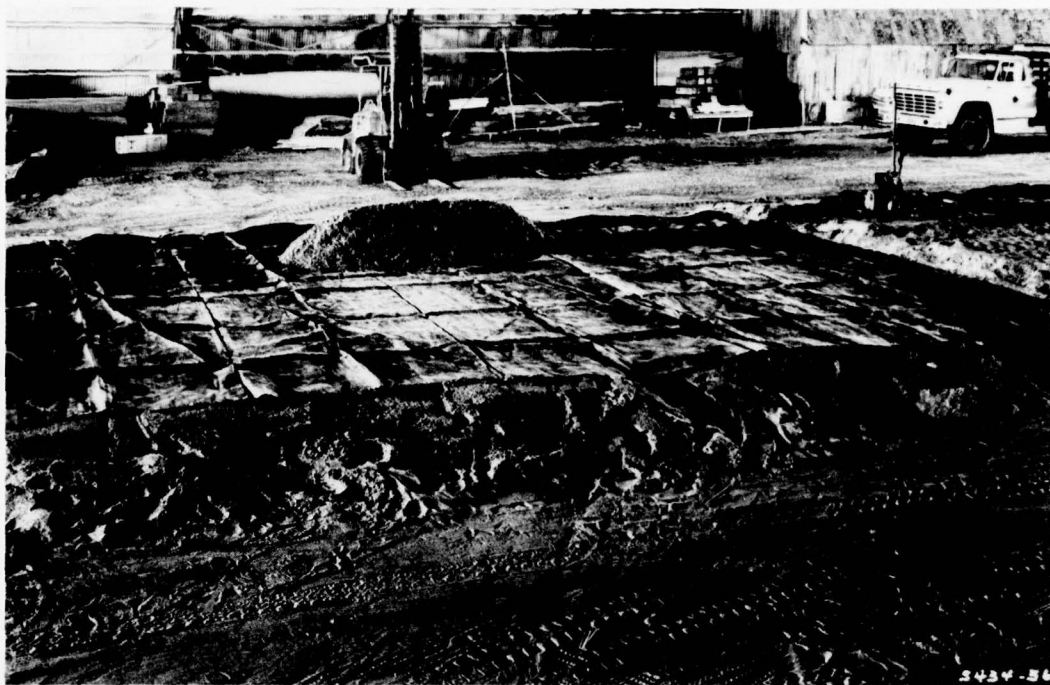


Photo 31. Construction of item 6A, test section 1



Photo 32. Item 6A prior to traffic, test section 1



Photo 33. Item 6A after 400 passes, test section 1



Photo 34. Membrane in item 6A after 900 passes,
test section 1

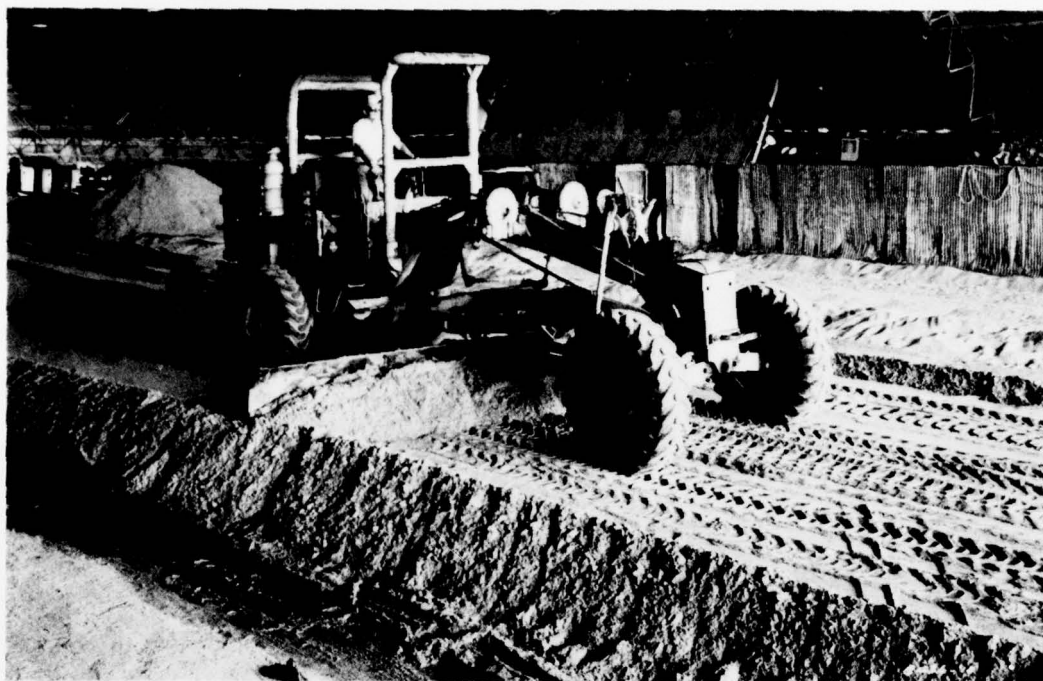


Photo 35. Blading excess grid sand to shoulder area,
test section 2

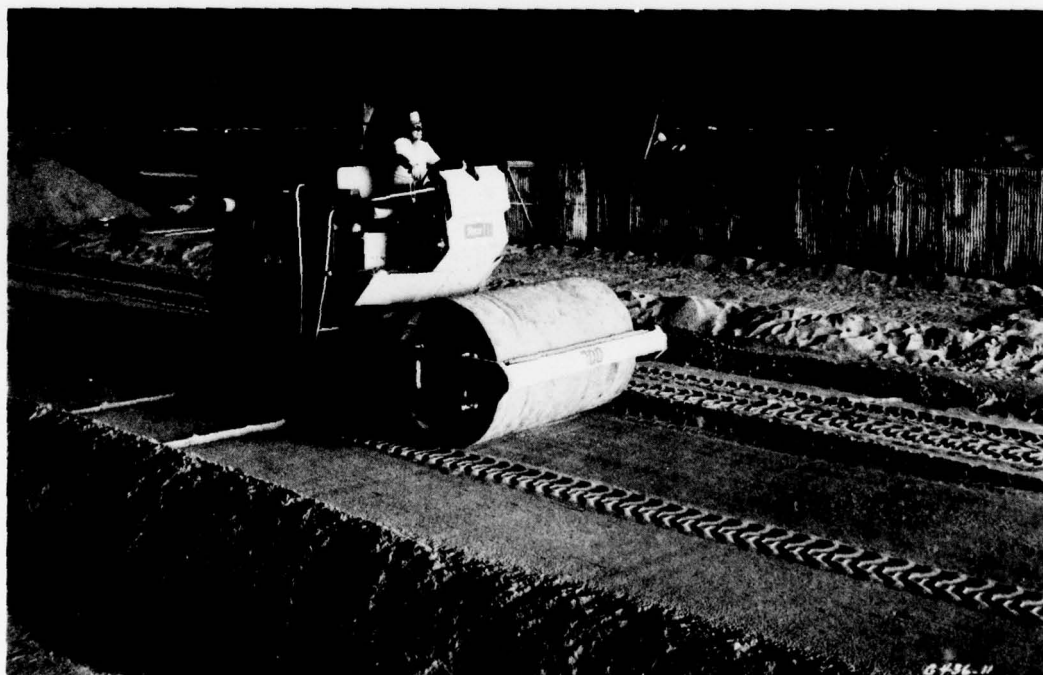


Photo 36. Compacting sand into grid cells using
vibratory drum roller, test section 2



Photo 37. Surface of item 1 after asphalt application,
test section 2

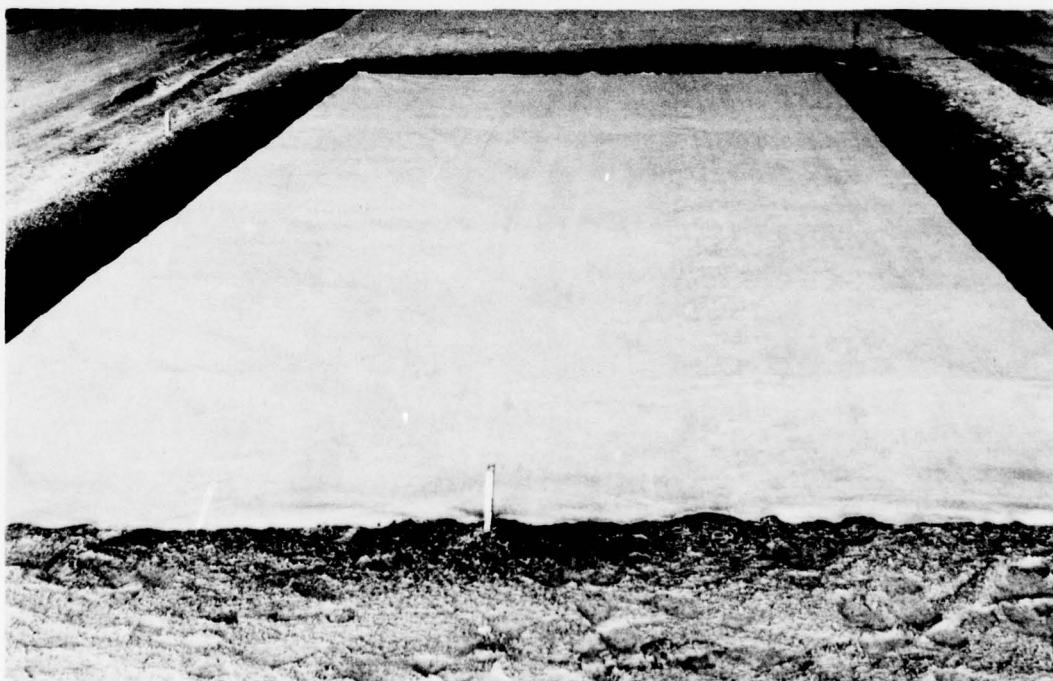


Photo 38. Polyester fabric in place on item 1,
test section 2



Photo 39. Spraying SS-1 asphalt on fabric, item 1,
test section 2

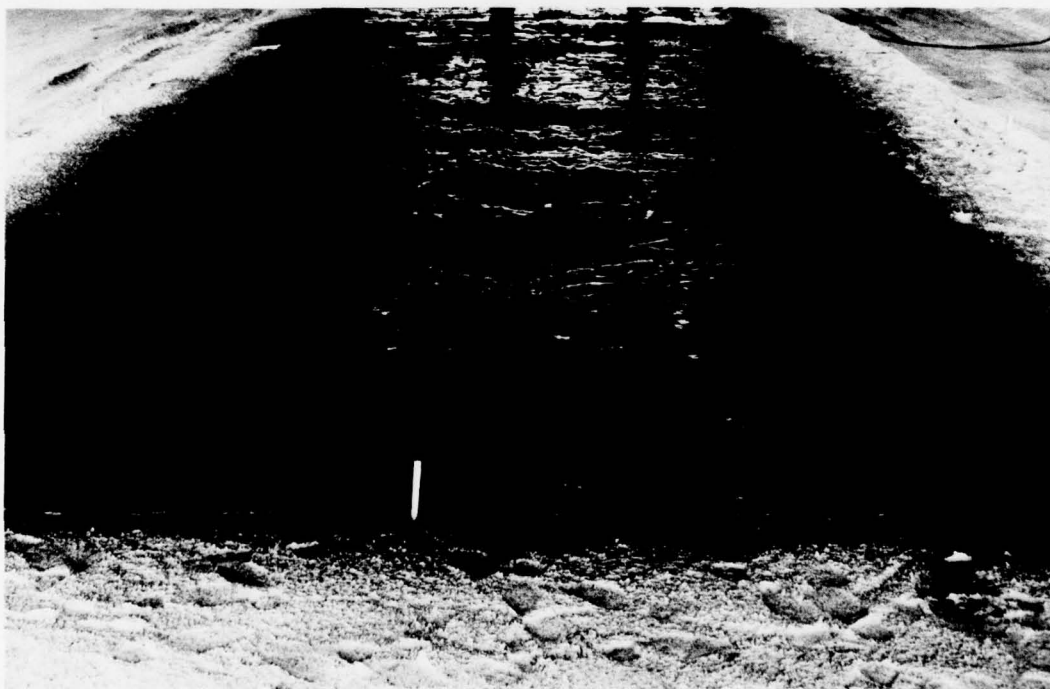


Photo 40. Asphalt-saturated fabric, item 1,
test section 2



Photo 41. Completed grid items prior to traffic tests,
test section 2



Photo 42. Construction of item 5, test section 2

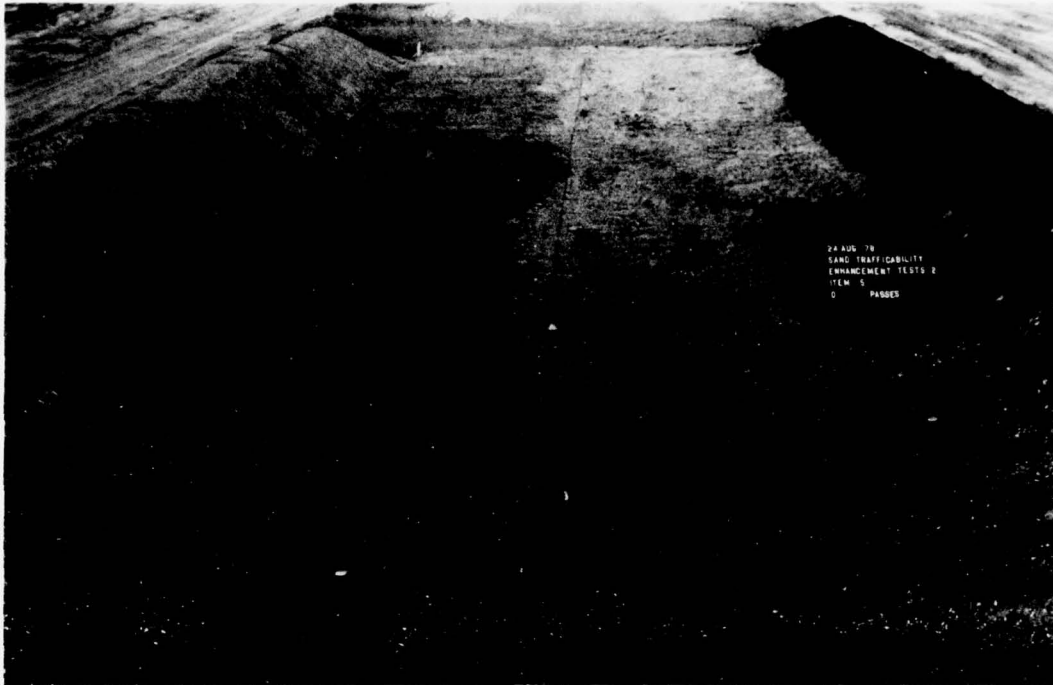


Photo 43. Completed item 5 prior to traffic tests,
test section 2



Photo 44. Item 1 after 100 passes, test section 2



Photo 45. Item 1 after 5000 passes, test section 2

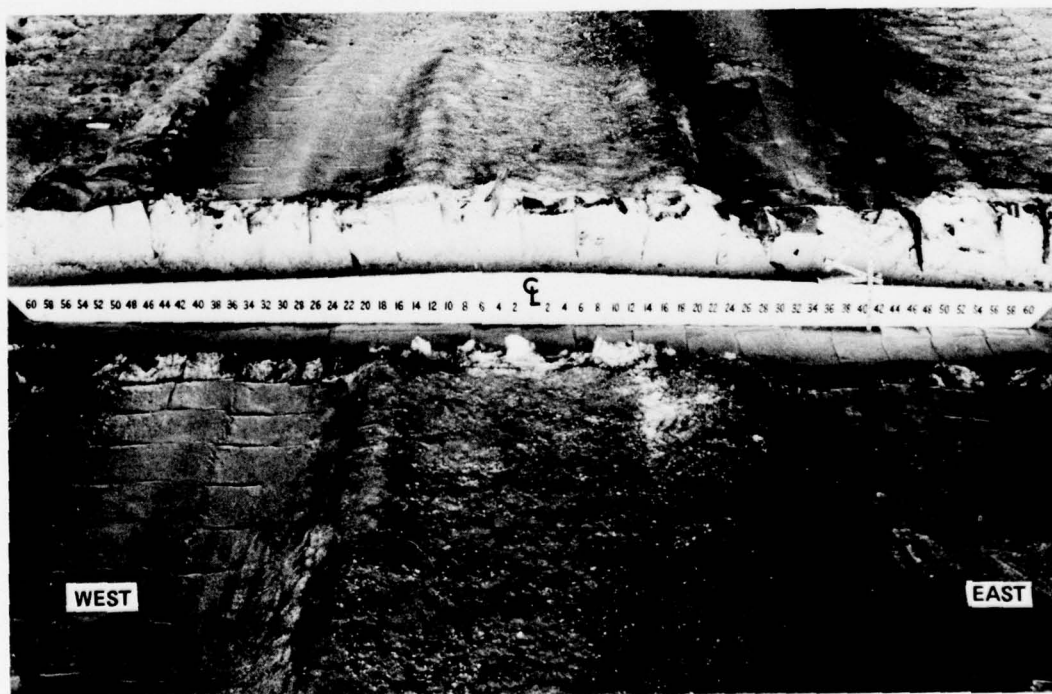


Photo 46. Trench cut across item 1 after 5000 passes,
test section 2

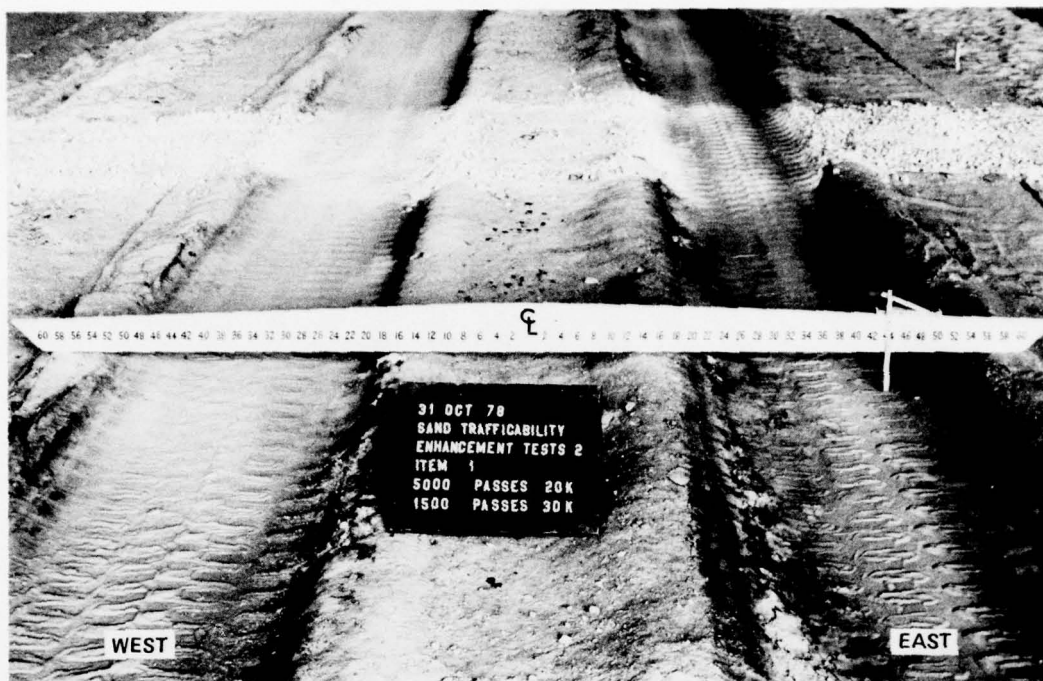


Photo 47. Item 1 after 6500 passes, test section 2



Photo 48. Item 2 after 100 passes, test section 2



Photo 49. Item 2 after 5000 passes, test section 2

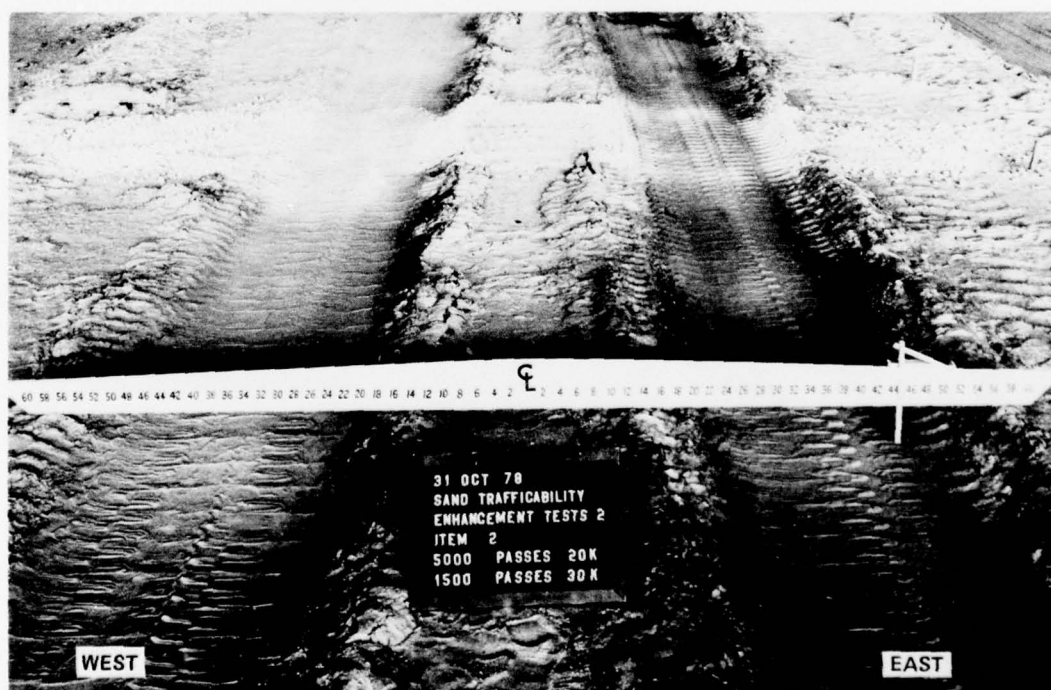


Photo 50. Item 2 after 6500 passes, test section 2



Photo 51. Item 3 after 100 passes, test section 2



Photo 52. Item 3 after 3000 passes, test section 2



Photo 53. Item 3 after 5000 passes, test section 2



Photo 54. Trench cut across item 3 after 5000 passes,
test section 2



Photo 55. Item 4 after 100 passes, test section 2



Photo 56. Item 4 after 3000 passes, test section 2



Photo 57. Item 4 after 5000 passes, test section 2

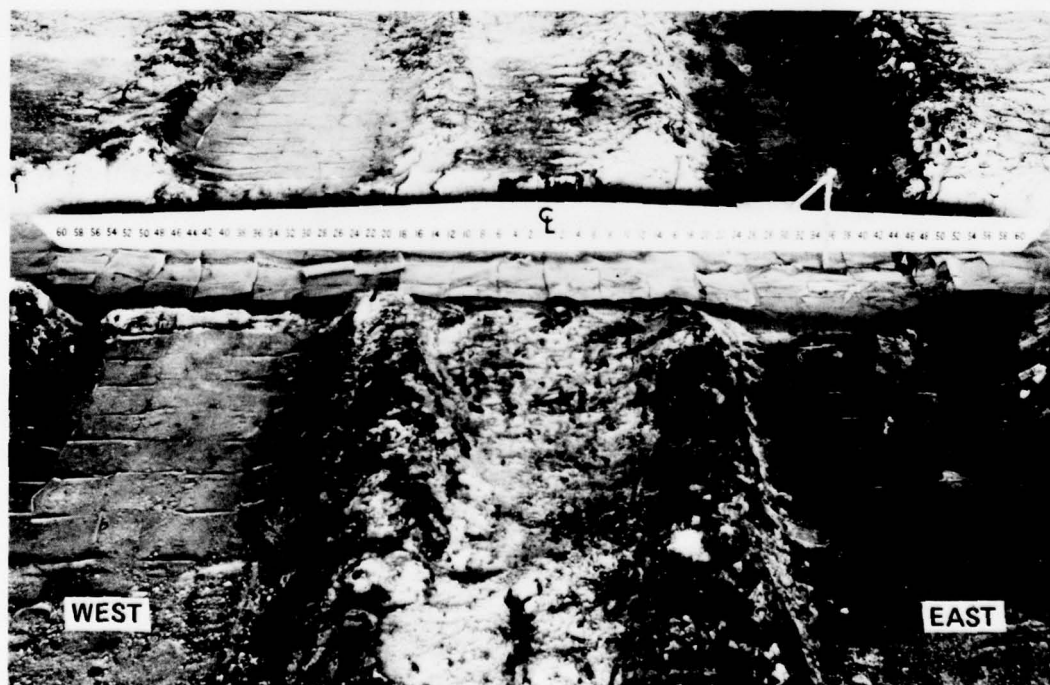


Photo 58. Trench cut across item 4 after 5000 passes, test section 2



Photo 59. Item 5 after 100 passes, test section 2

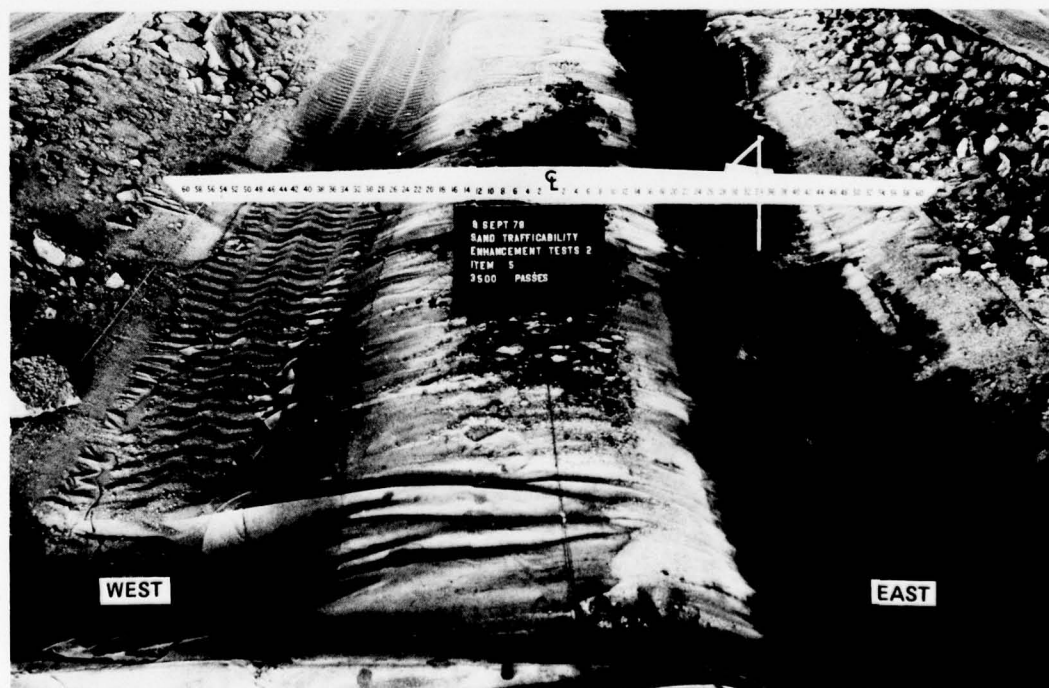
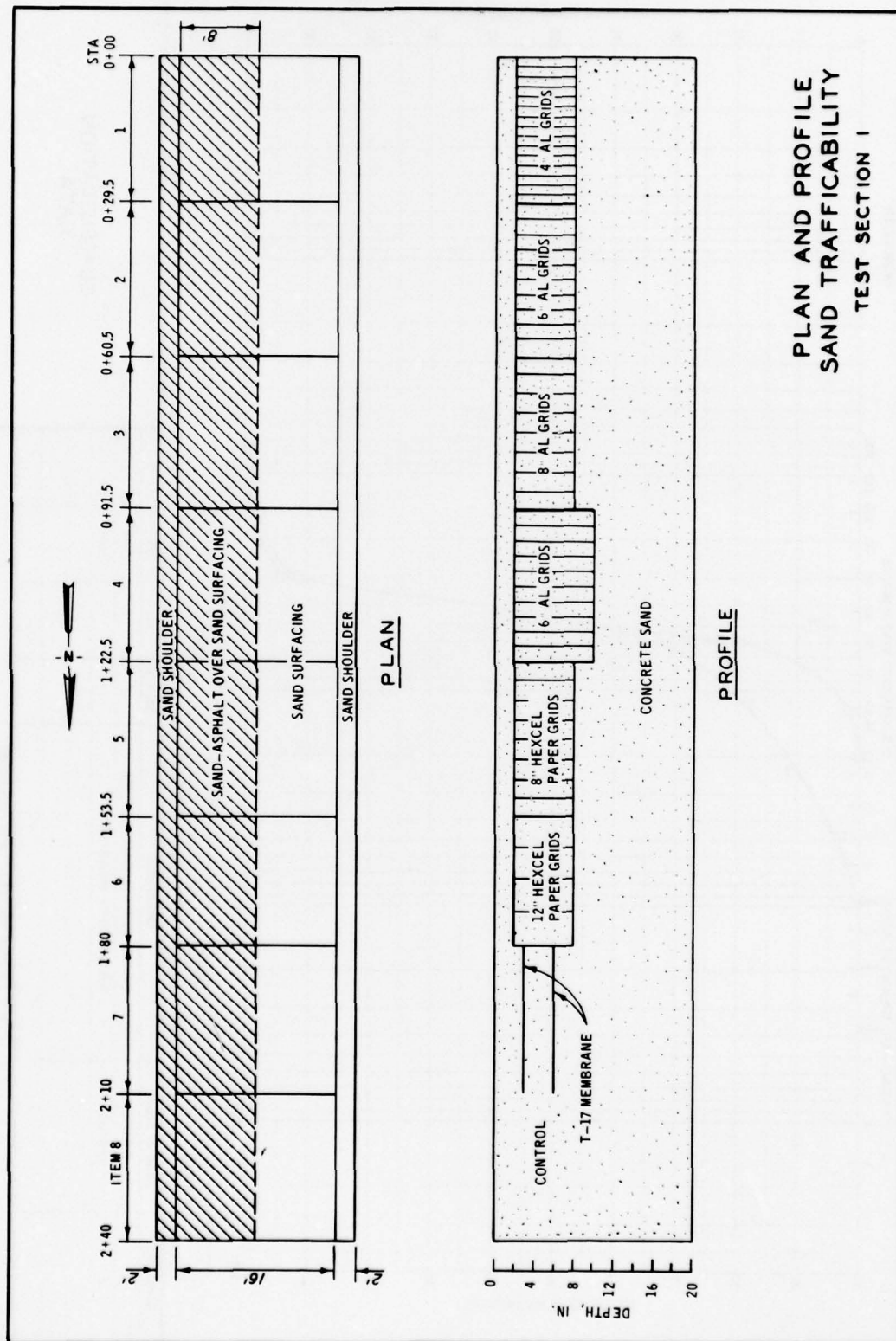


Photo 60. Item 5 after 3500 passes, test section 2

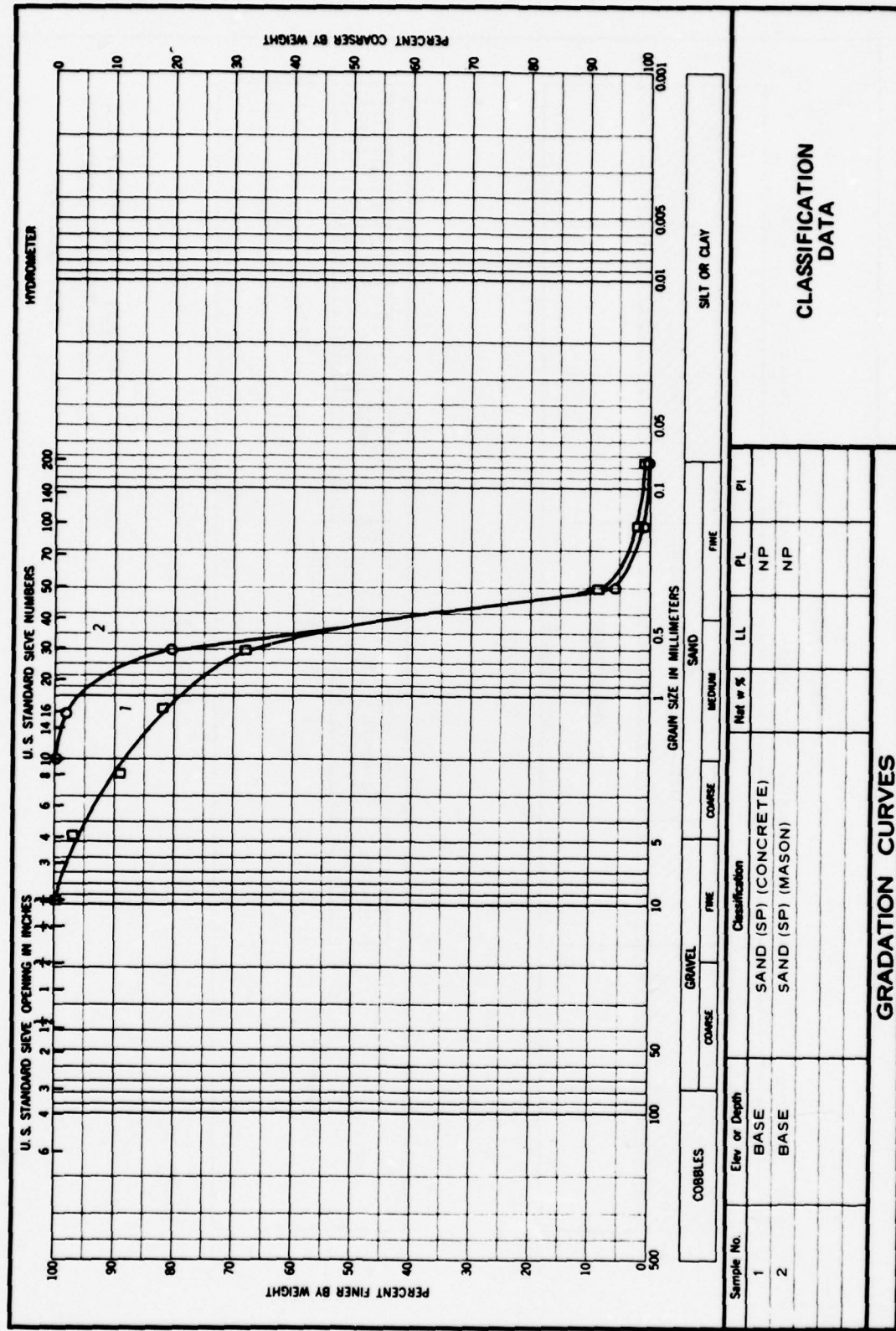


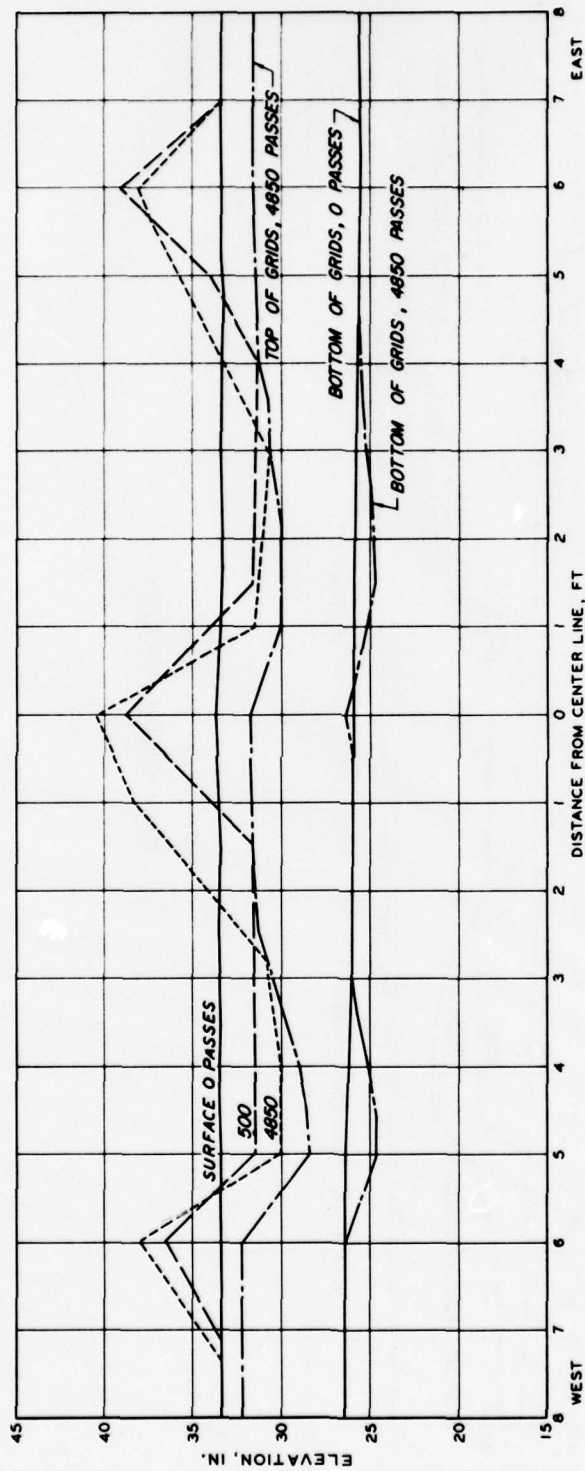
Photo 61. Section view of item 5 after surfacing sand and top membrane were removed at 3500 passes, test section 2



PLAN AND PROFILE
SAND TRAFFICABILITY
TEST SECTION I

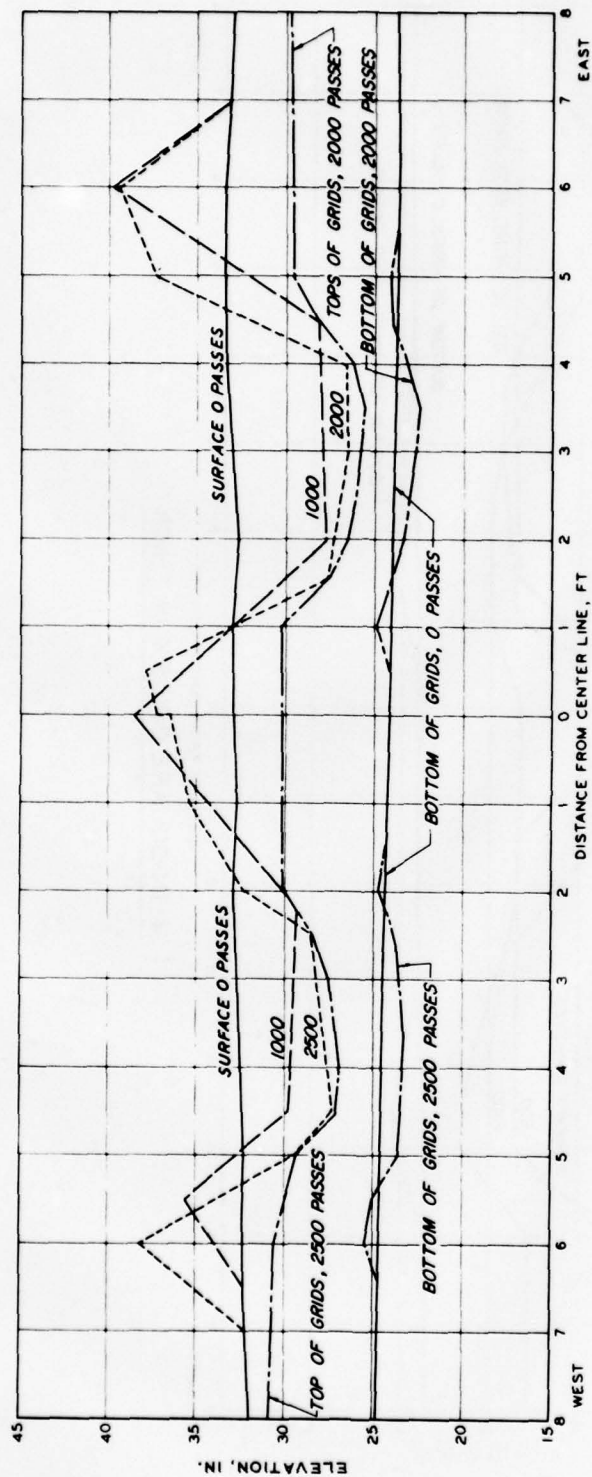
PLATE 2





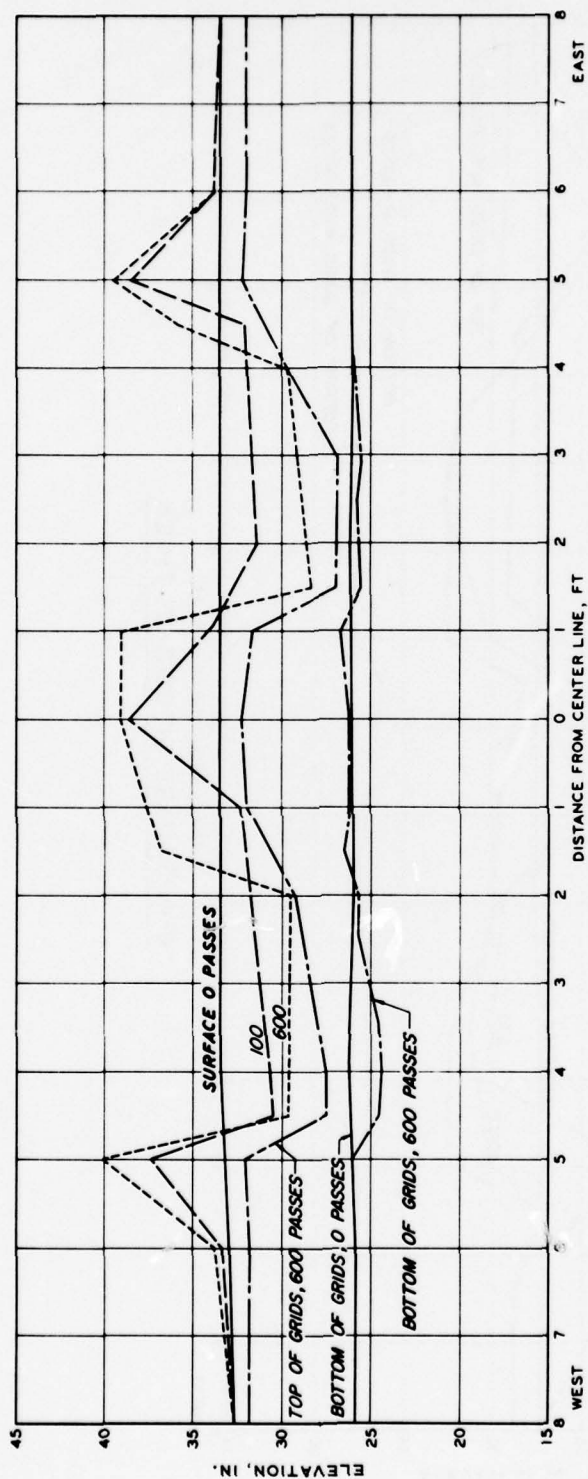
4-IN-SQUARE GRIDS, 6 IN. THICK

TYPICAL CROSS SECTION
TEST SECTION I
ITEM 1, STA 0+15



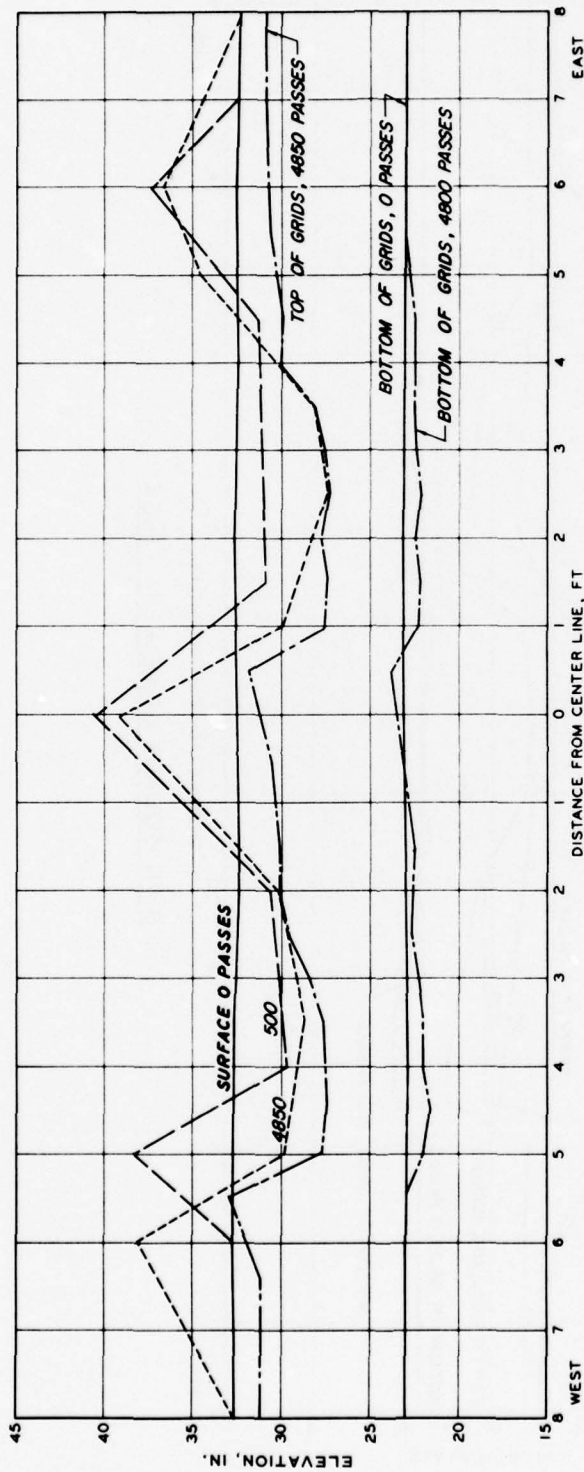
6-IN.-CUBIC GRIDS

TYPICAL CROSS SECTION
TEST SECTION I
ITEM 2, STA 0+37



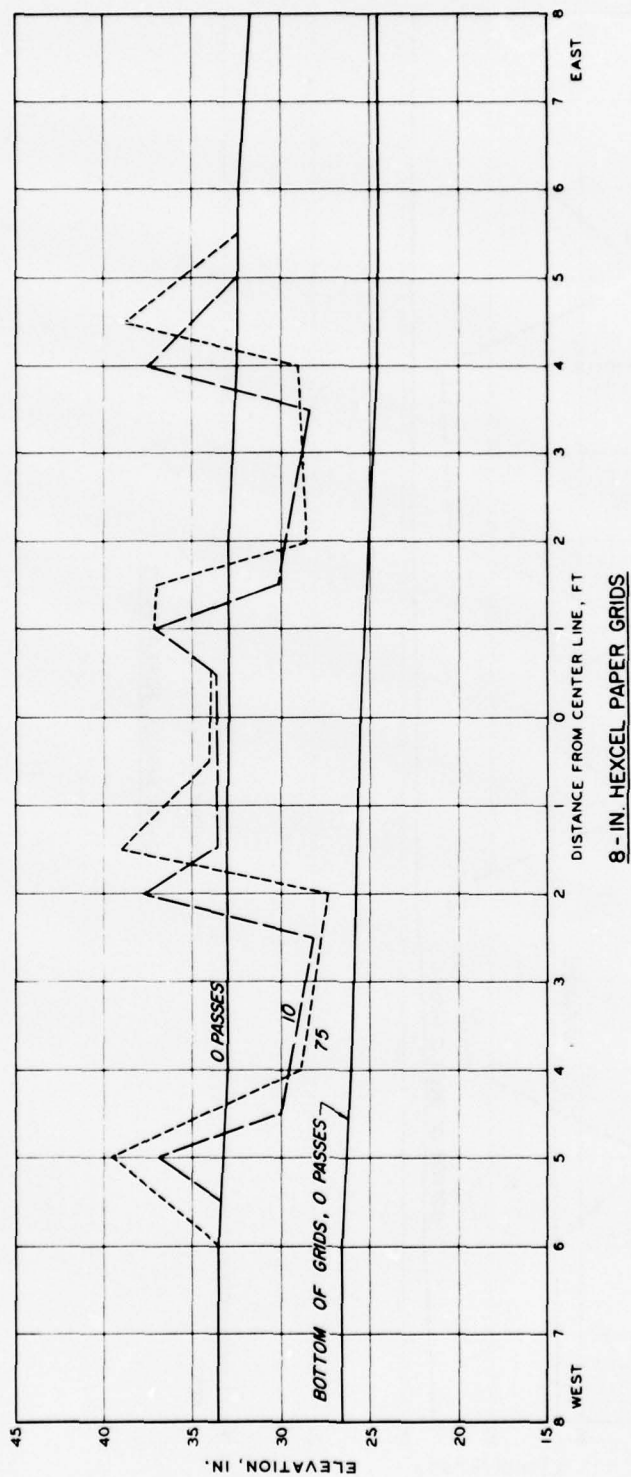
8-IN.-SQUARE GRIDS, 6-IN. THICK

TYPICAL CROSS SECTION
TEST SECTION 1
ITEM 3, STA 0+83



6-IN-SQUARE GRIDS, 8-IN. THICK

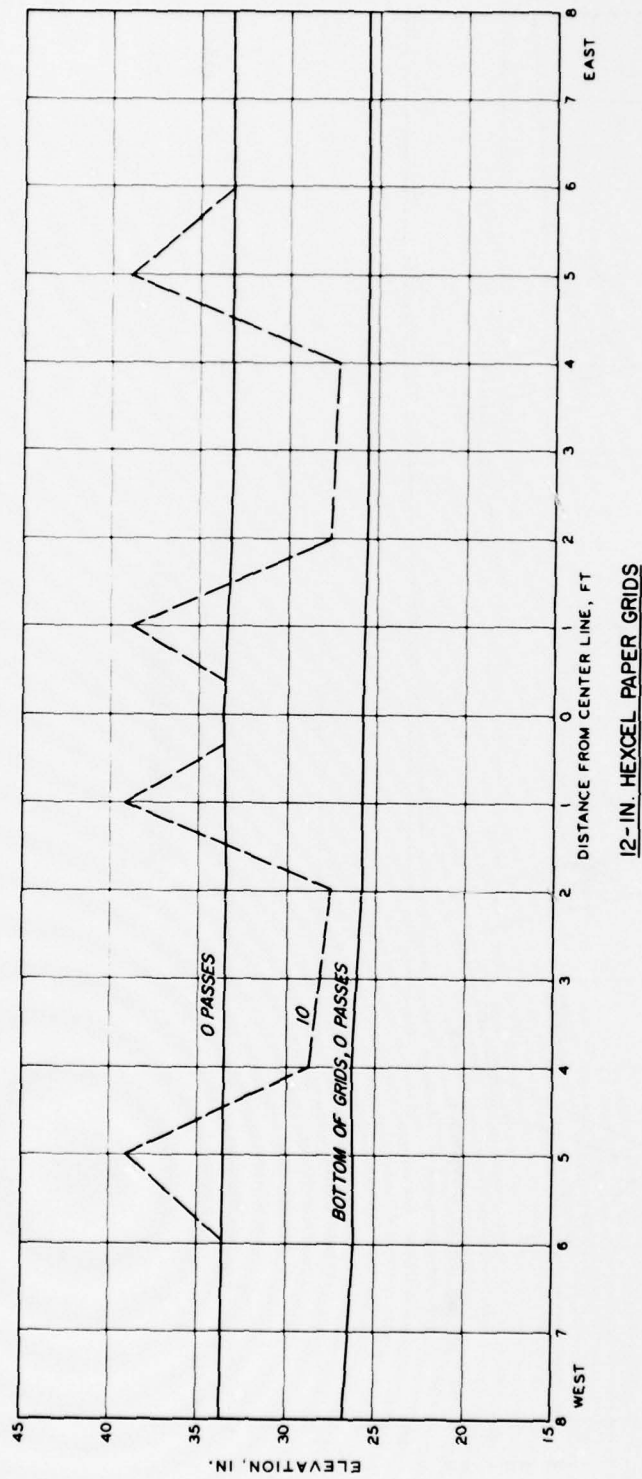
TYPICAL CROSS SECTION
TEST SECTION I
ITEM 4, STA 1+14



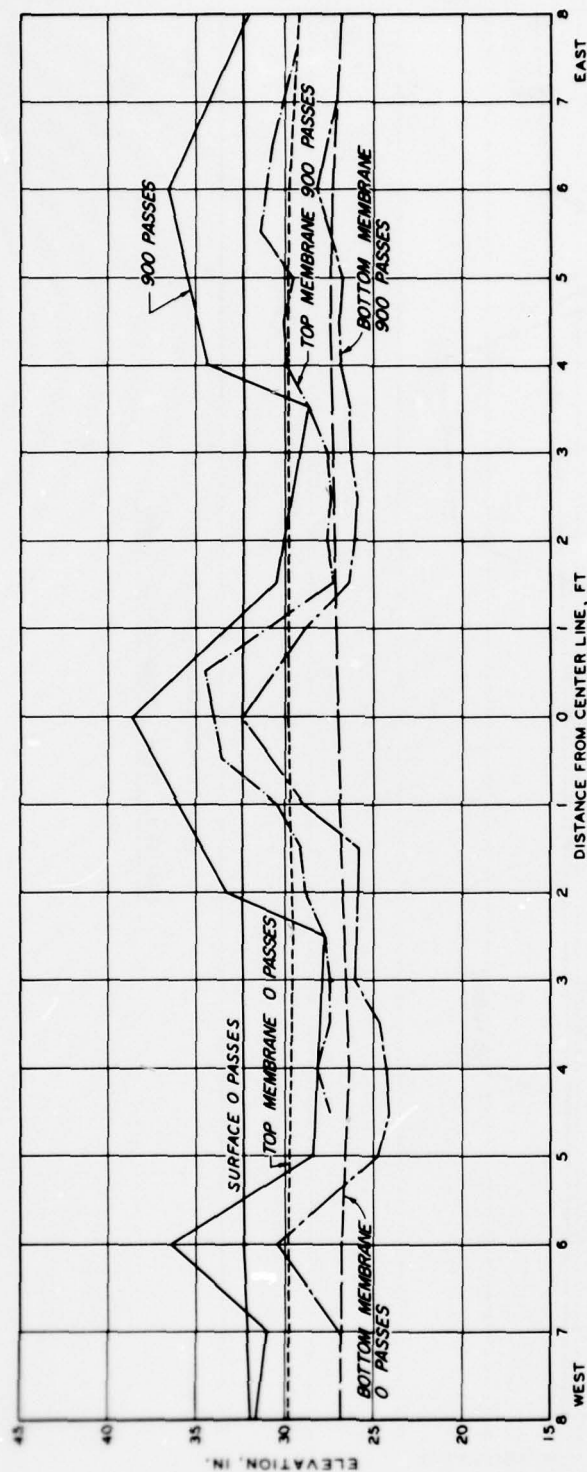
8-IN. HEXCEL PAPER GRIDS

TYPICAL CROSS SECTION
TEST SECTION I
ITEM 5, STA 1+37.5

PLATE 8

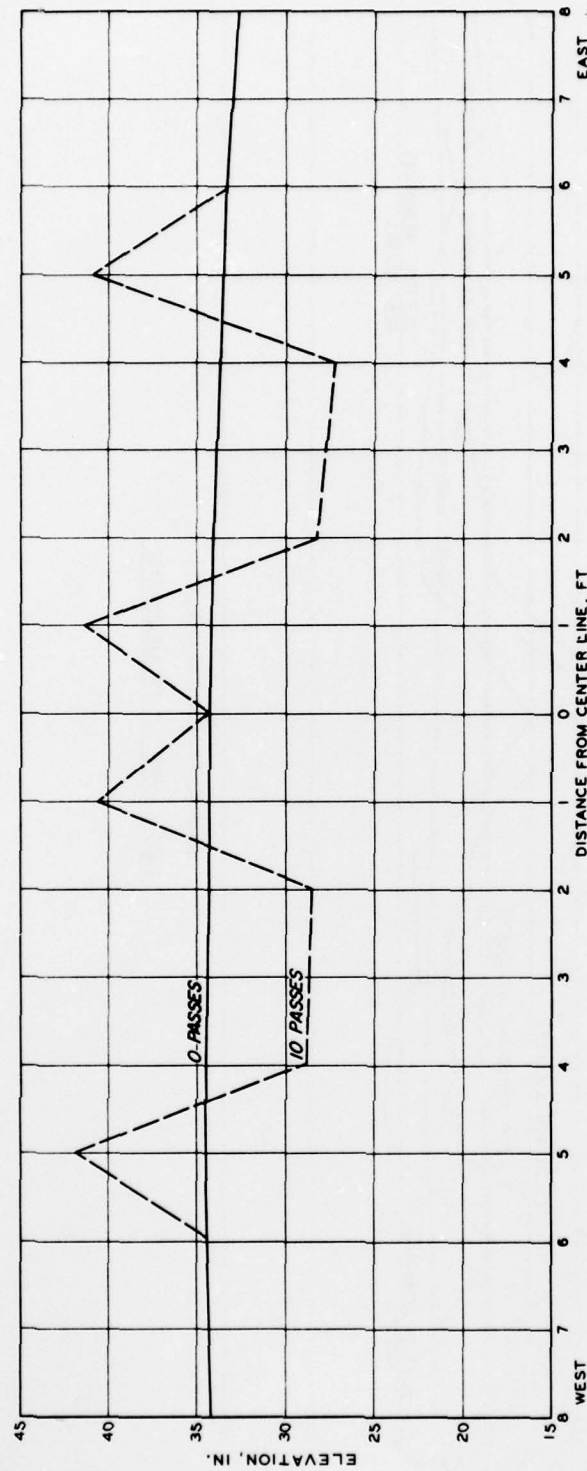


TYPICAL CROSS SECTION
TEST SECTION I
ITEM 6, STA 1+61



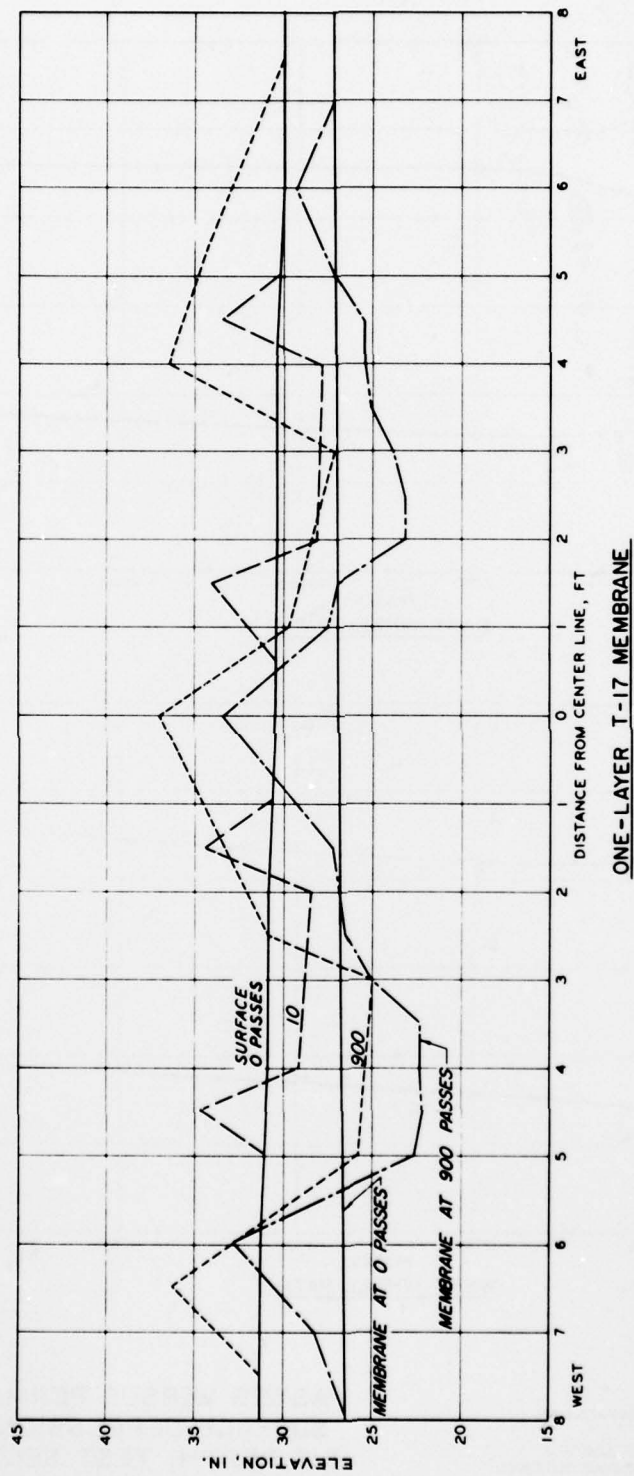
TWO-LAYER T-17 MEMBRANE

TYPICAL CROSS SECTION
TEST SECTION I
ITEM 7, STA 1+95

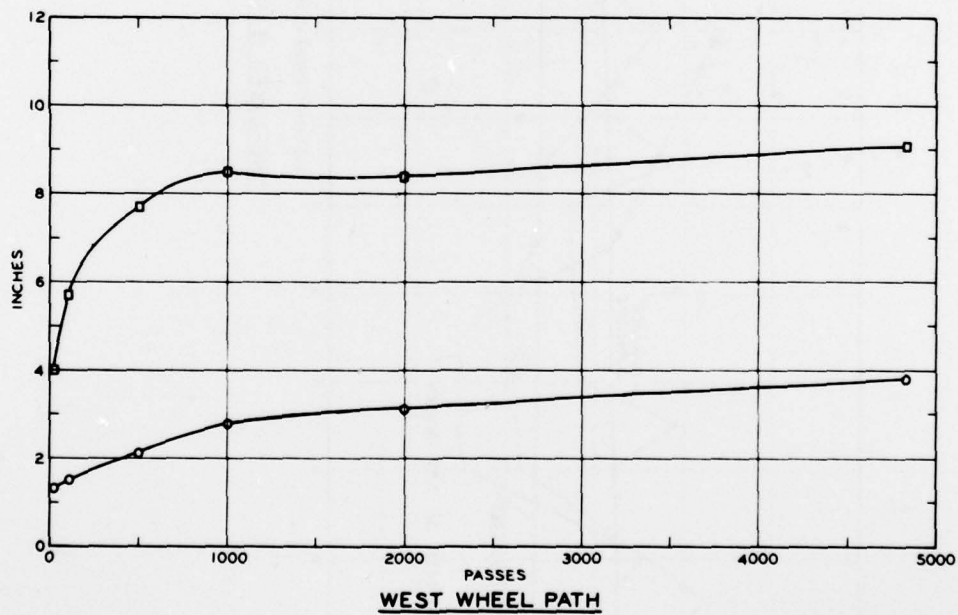
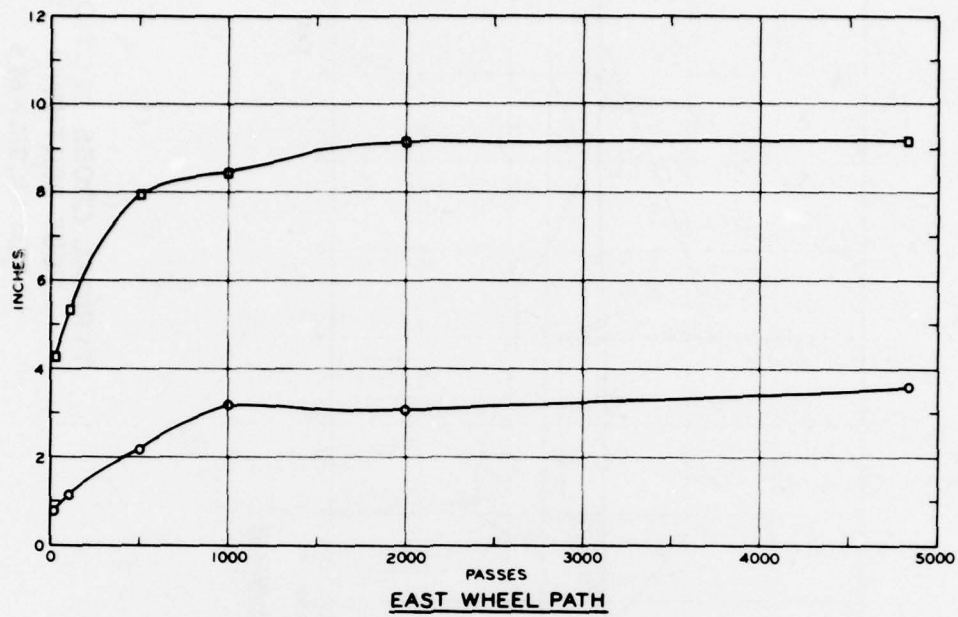


CONTROL ITEM, COMPACTED SAND

TYPICAL CROSS SECTION
TEST SECTION I
ITEM 8, STA 2+25



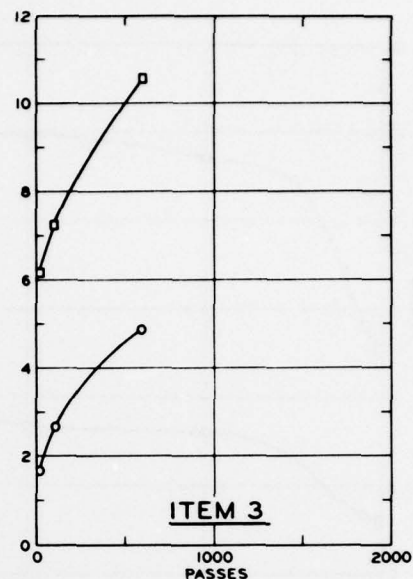
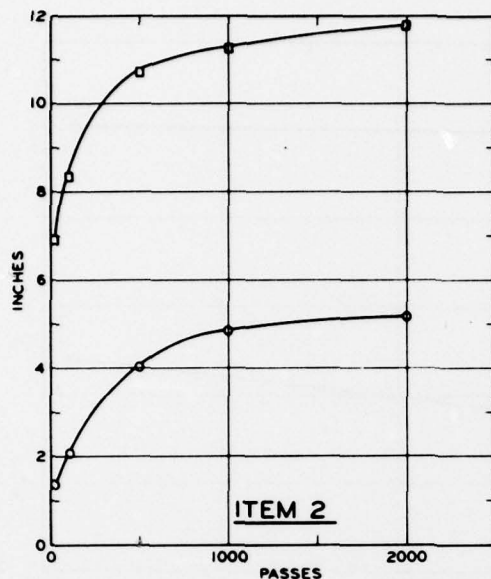
TYPICAL CROSS SECTION
TEST SECTION I
ITEM 6A, STA 1+67.5



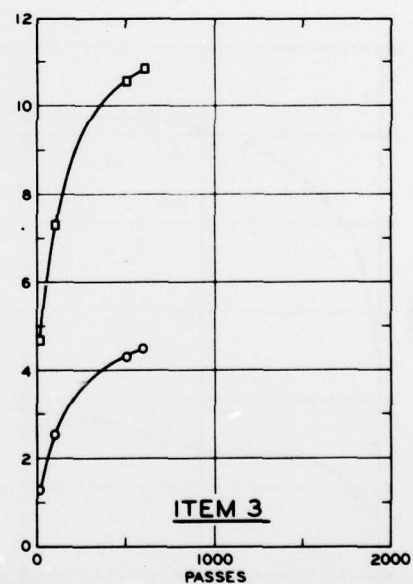
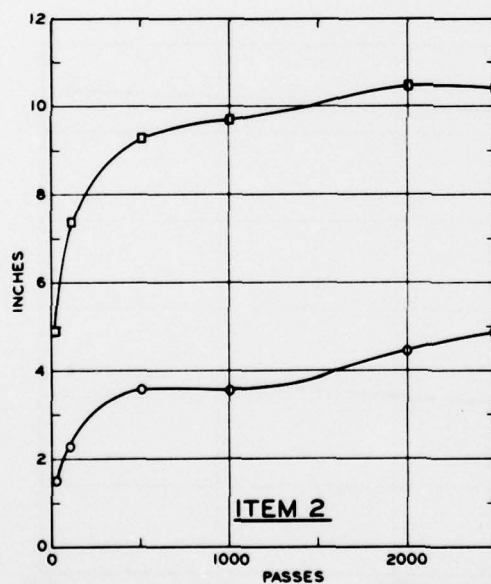
LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

**PASSES VERSUS PERMANENT
SURFACE DEPRESSION AND
RUT DEPTH, TEST SECTION I
ITEM 1**



EAST WHEEL PATH

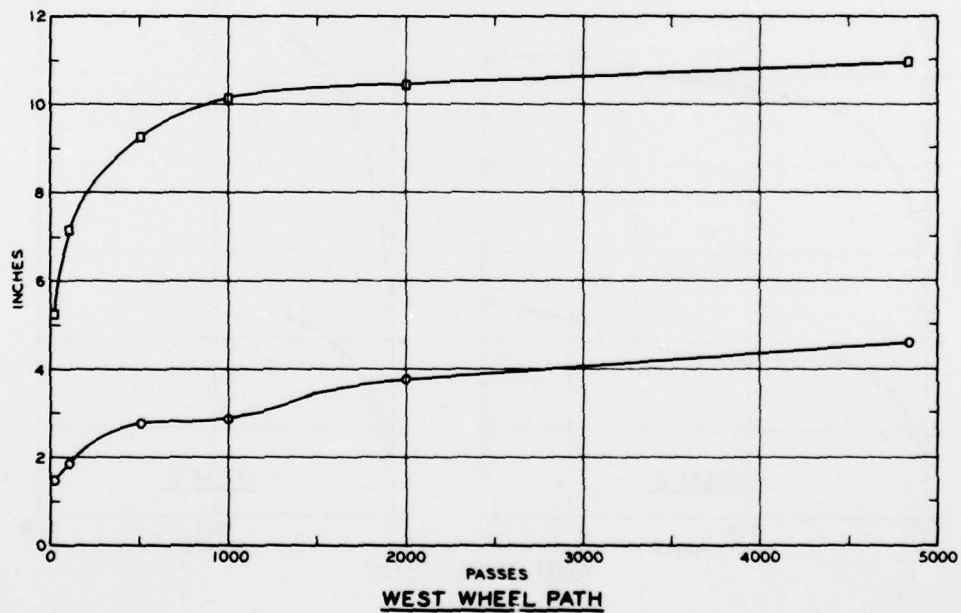
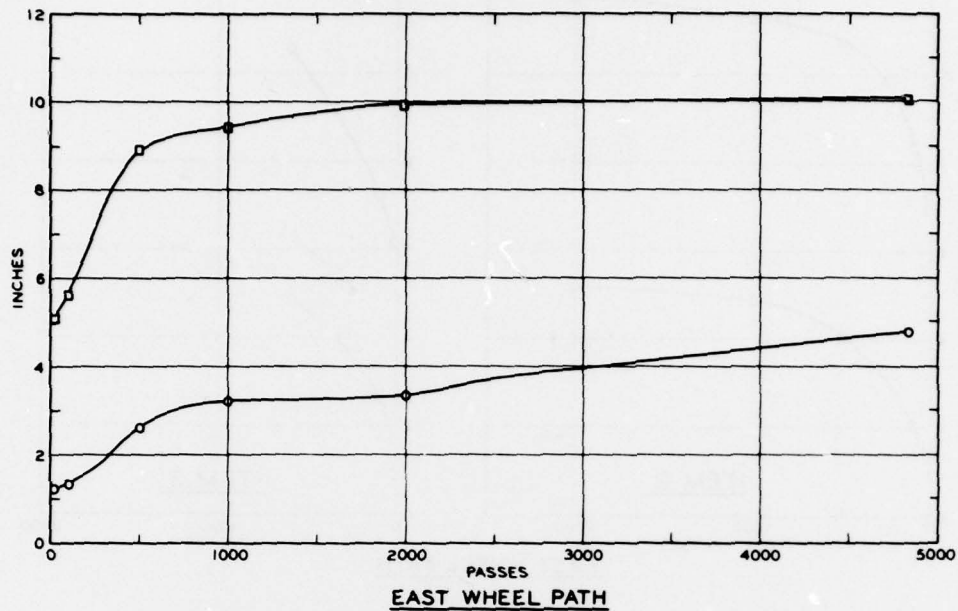


WEST WHEEL PATH

LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

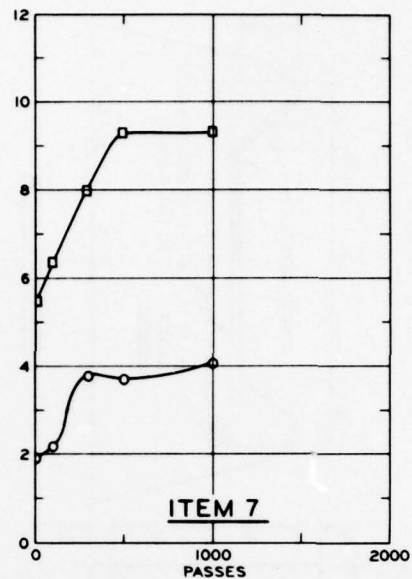
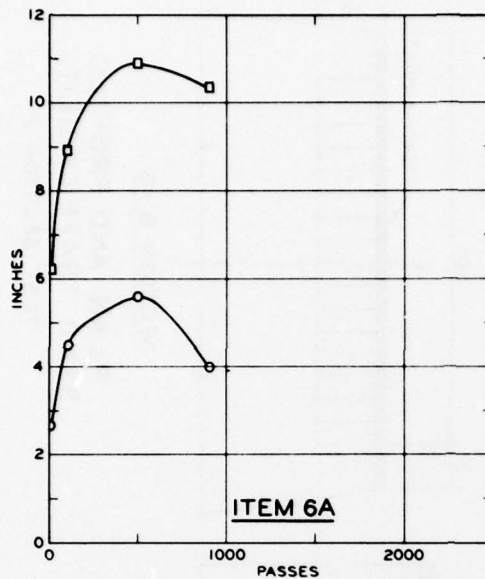
**PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION I
ITEMS 2 AND 3**



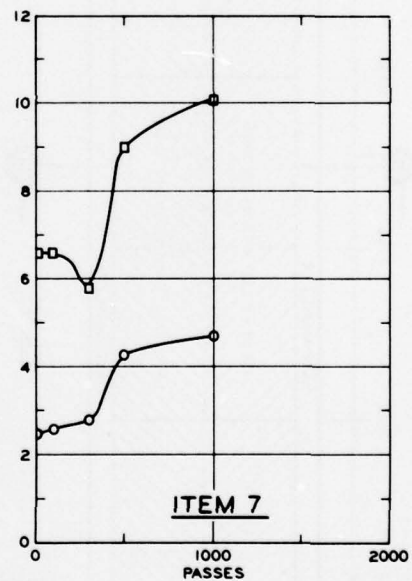
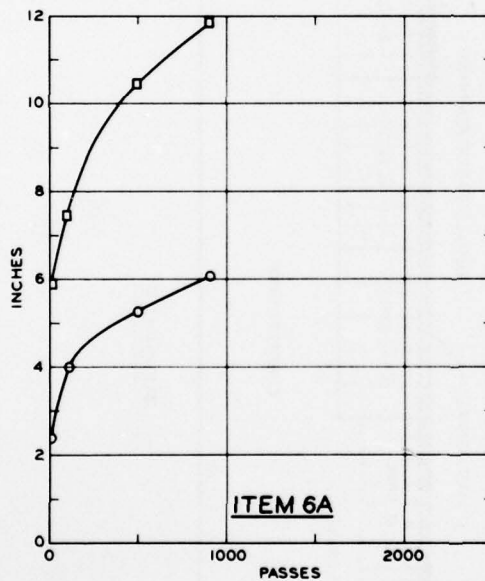
LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

**PASSES VERSUS PERMANENT
SURFACE DEPRESSION AND
RUT DEPTH, TEST SECTION 1
ITEM 4**



EAST WHEEL PATH

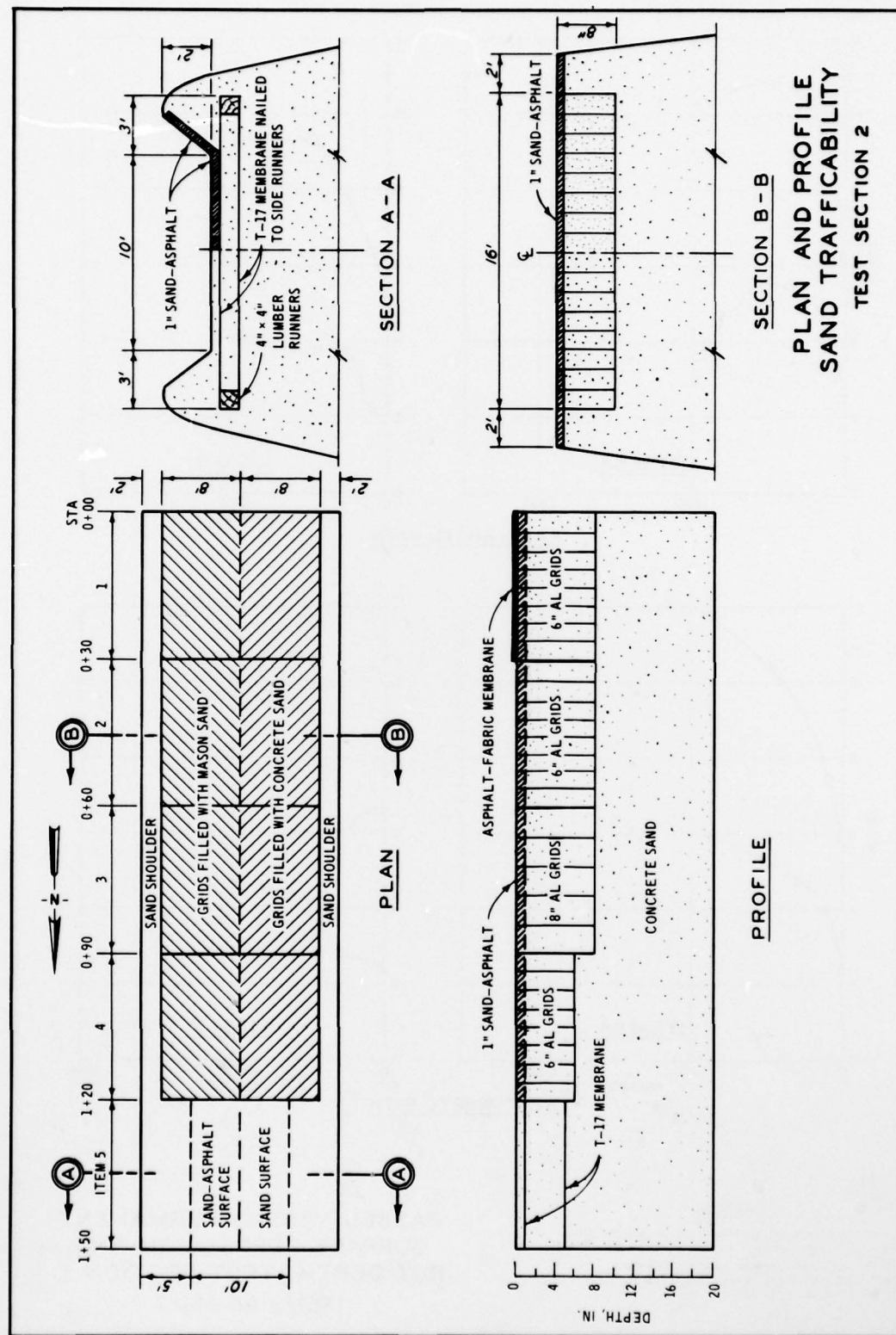


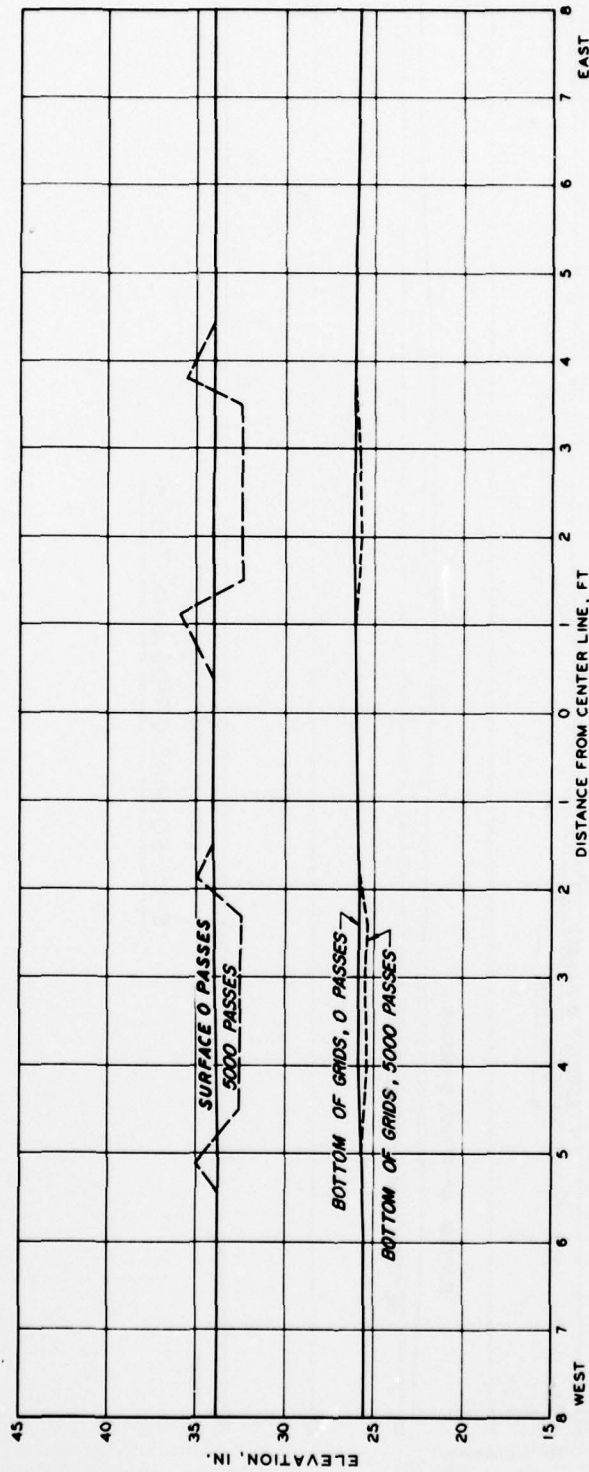
WEST WHEEL PATH

LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

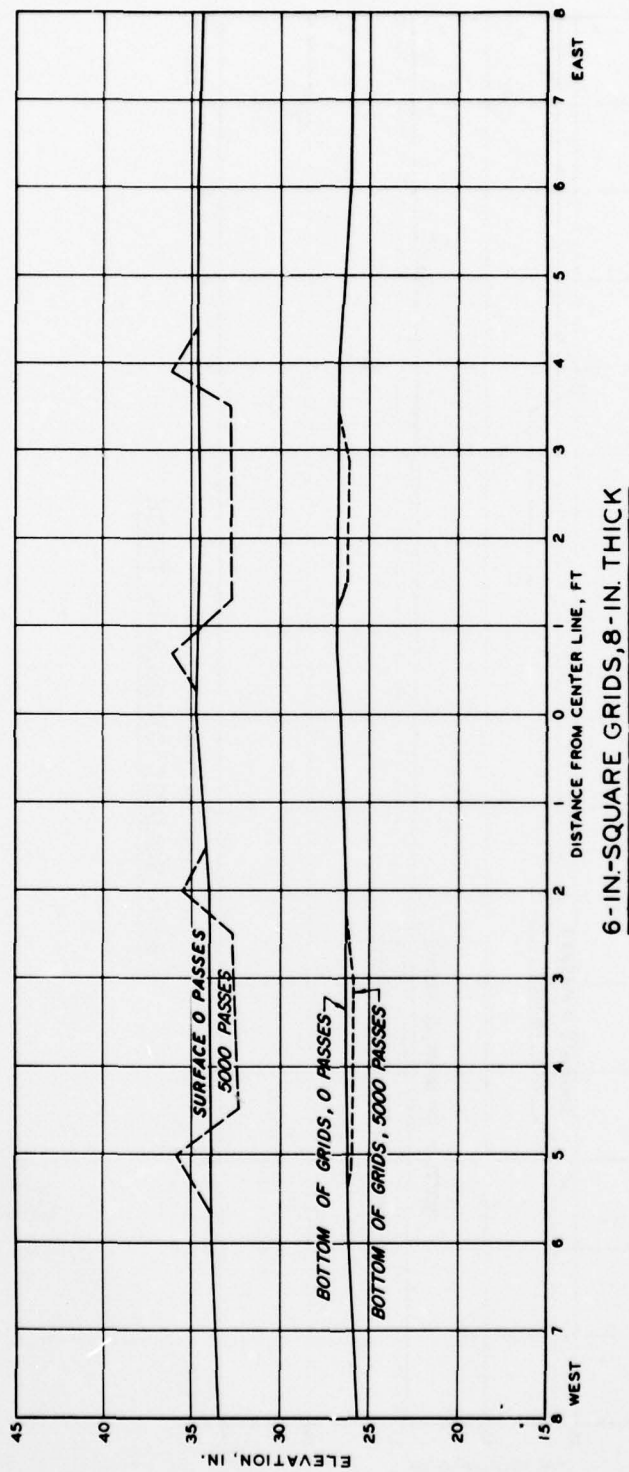
PASSES VERSUS PERMANENT
SURFACE DEPRESSION AND
RUT DEPTH, TEST SECTION I
ITEMS 6A AND 7



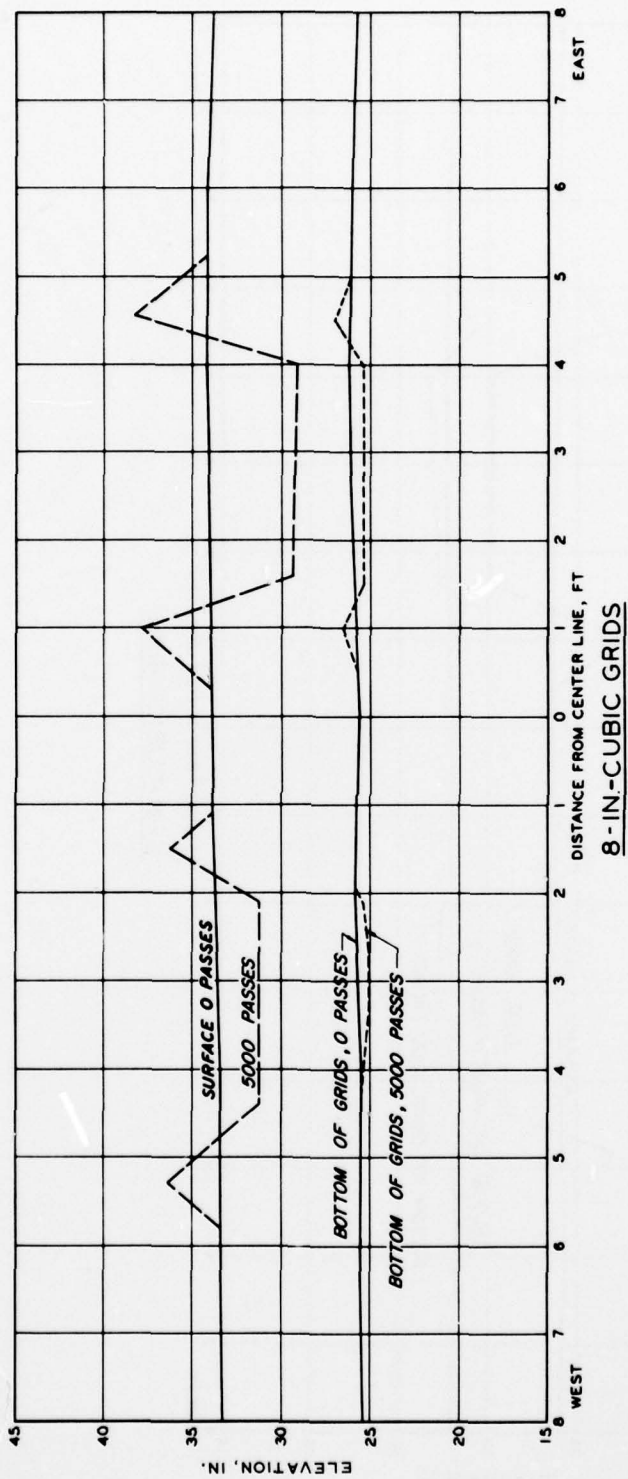


6-IN.-SQUARE GRIDS, 8-IN. THICK

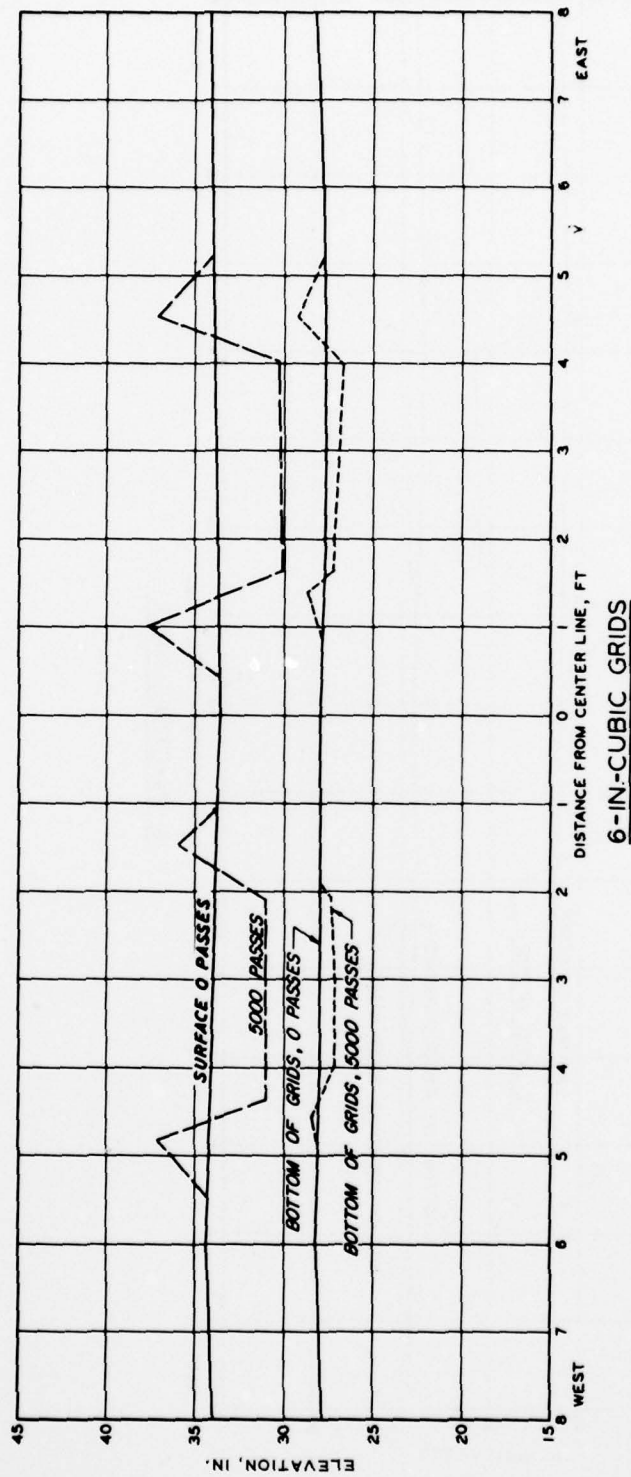
TYPICAL CROSS SECTION
TEST SECTION 2
ITEM 1, STA 0+15



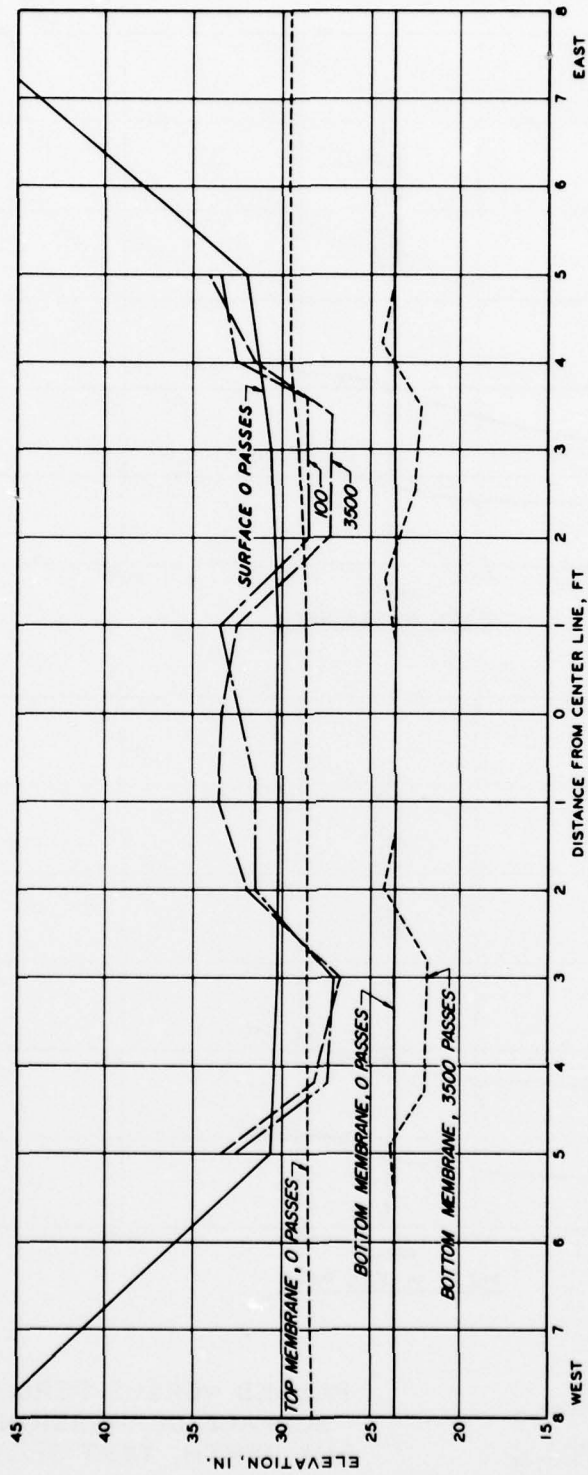
TYPICAL CROSS SECTION
TEST SECTION 2
ITEM 2, STA 0+46



TYPICAL CROSS SECTION
TEST SECTION 2
ITEM 3, STA 0+77



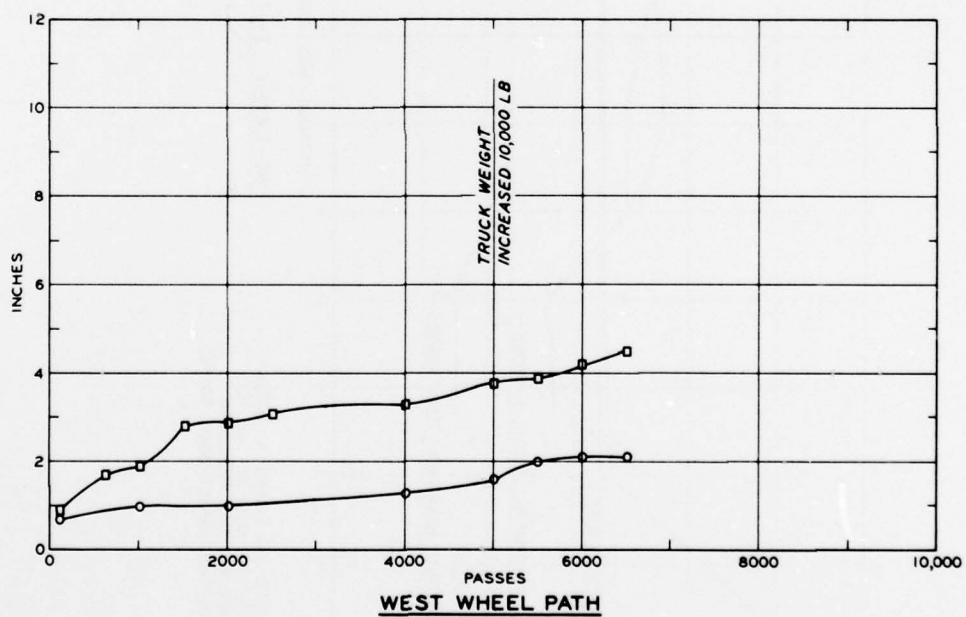
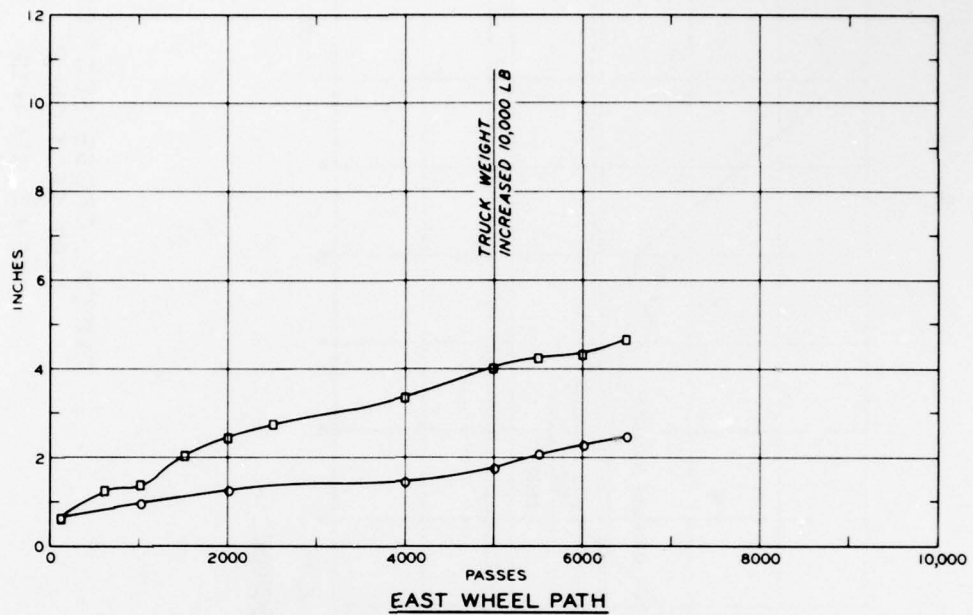
TYPICAL CROSS SECTION
TEST SECTION 2
ITEM 4, STA 1+00.5



TWO-LAYER T-17 MEMBRANE

NOTE: PHOTO 60 SHOWS A CROSS SECTION VIEW OF THE TOP AND BOTTOM MEMBRANE POSITION AFTER 3500 PASSES.

TYPICAL CROSS SECTION
TEST SECTION 2
ITEM 5, STA 1+39



LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

**PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 2
ITEM 1**

AD-A078 652

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/3
INVESTIGATION OF BEACH SAND TRAFFICABILITY ENHANCEMENT USING SA--ETC(U)
NOV 79 S L WEBSTER
WES/6L-79-20

UNCLASSIFIED

NL

2 OF 2
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A078652

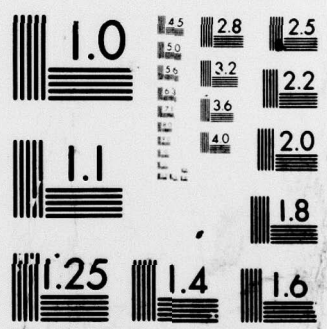


END

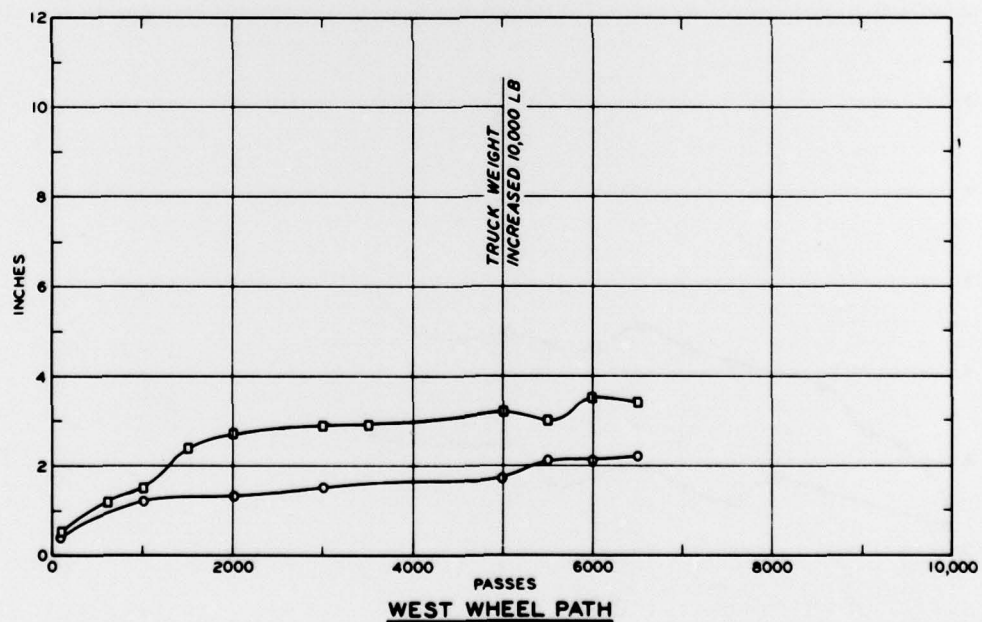
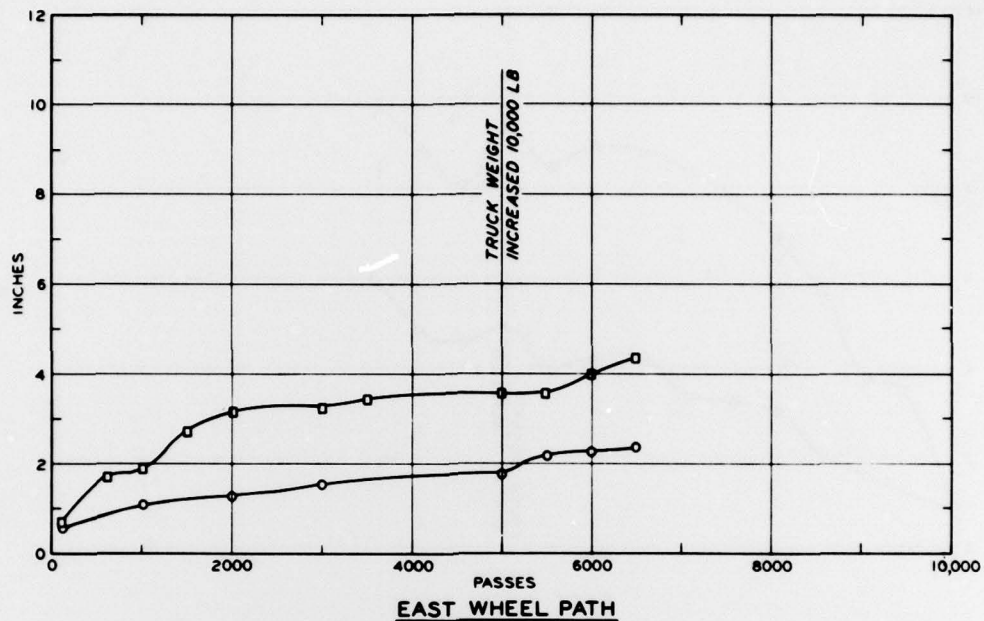
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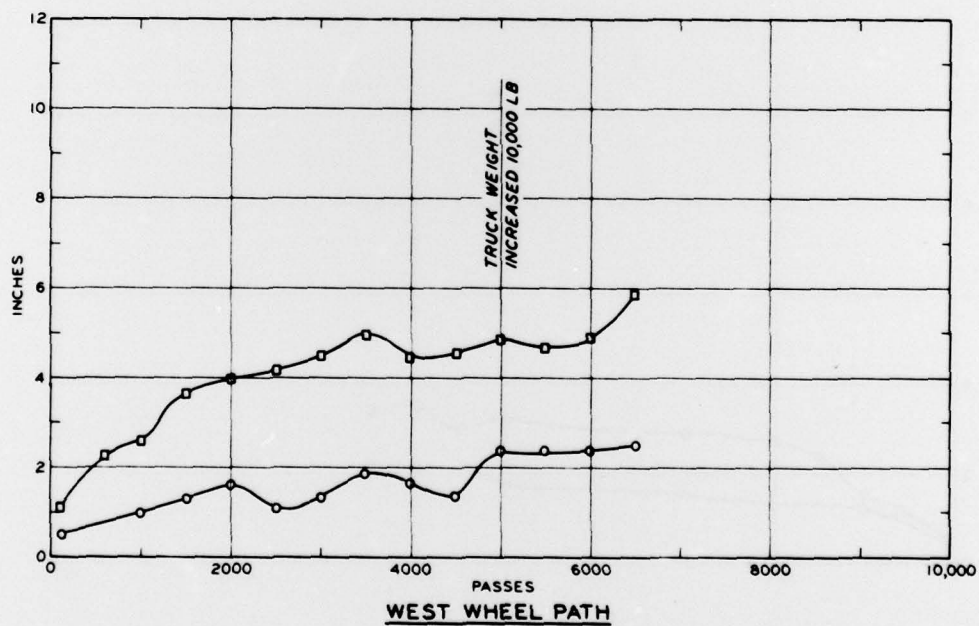
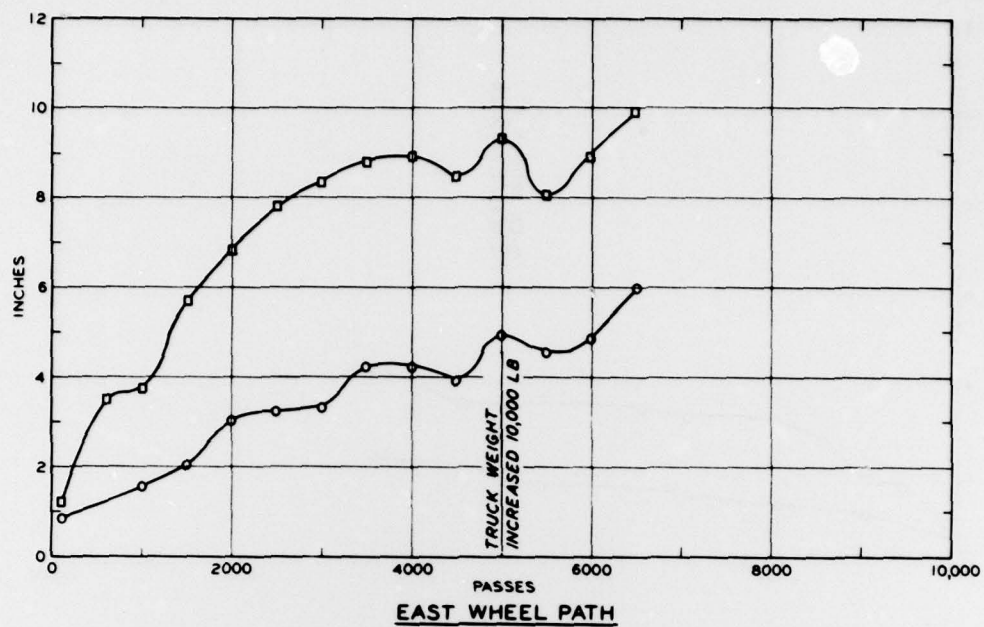
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

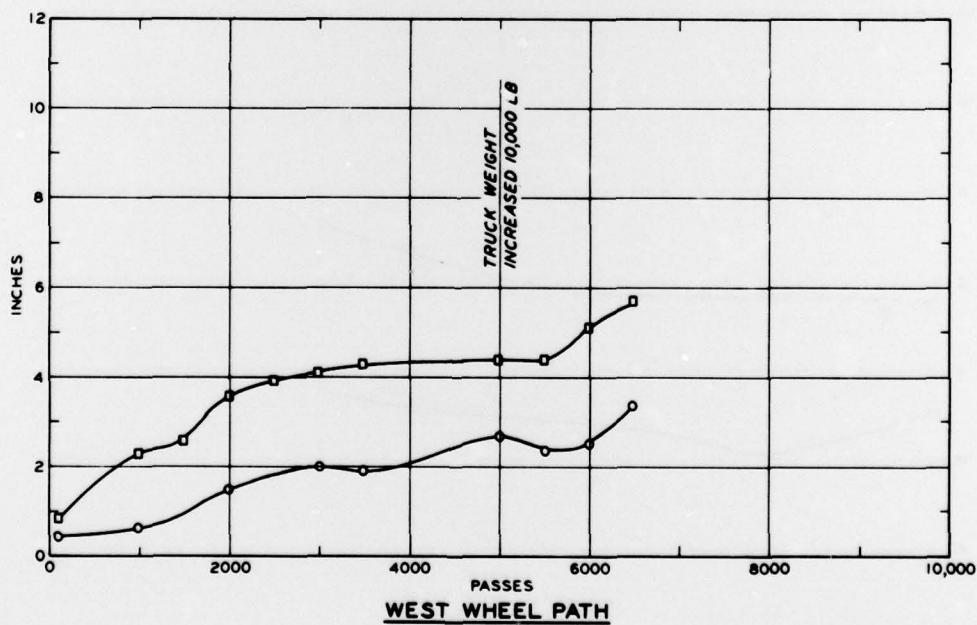
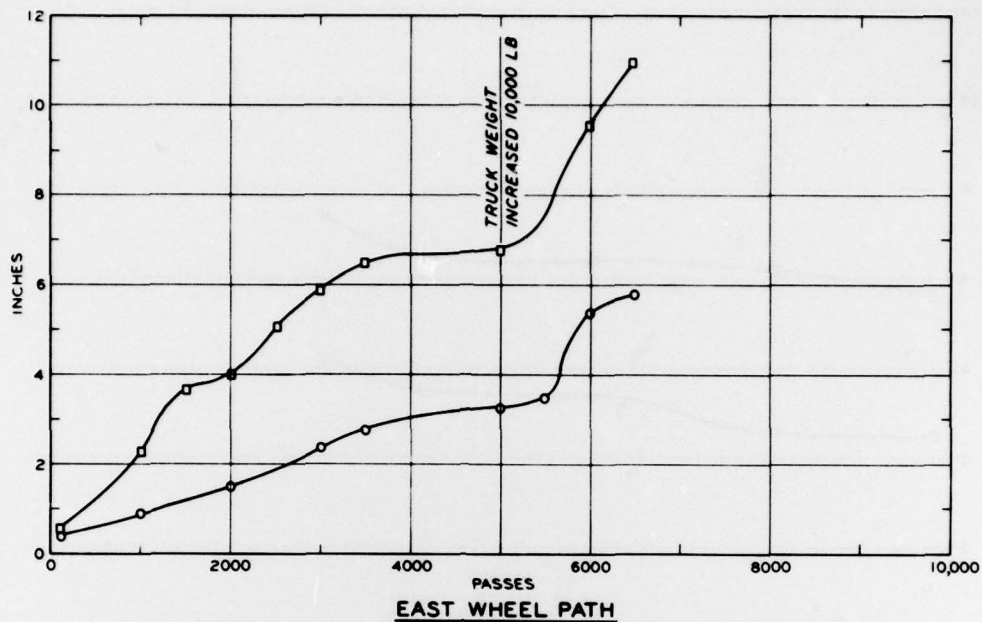
**PASSES VERSUS PERMANENT
SURFACE DEPRESSION AND
RUT DEPTH, TEST SECTION 2
ITEM 2**



LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

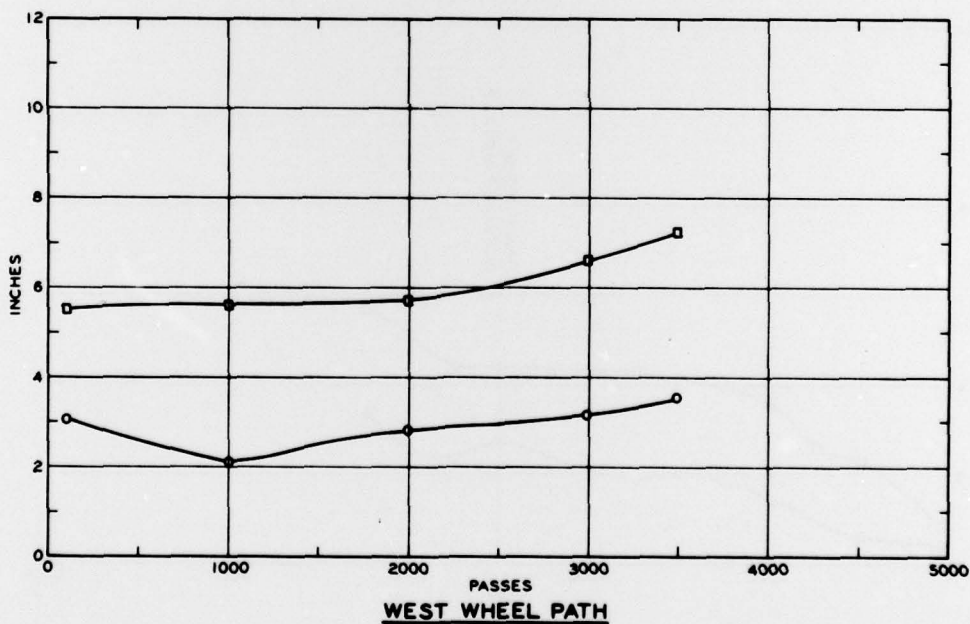
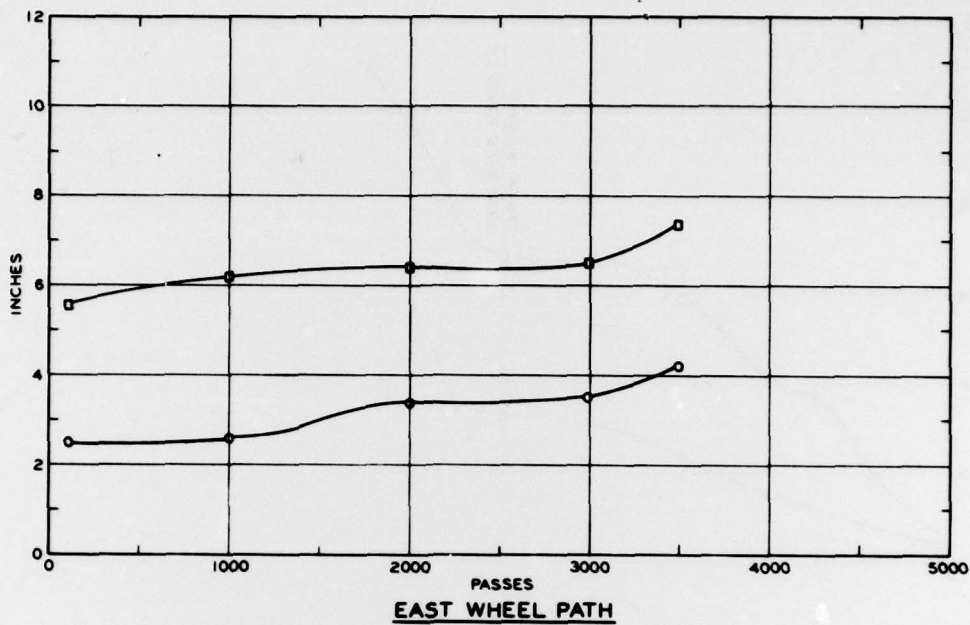
**PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 2
ITEM 3**



LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

**PASSES VERSUS PERMANENT SURFACE DEPRESSION AND RUT DEPTH, TEST SECTION 2
ITEM 4**



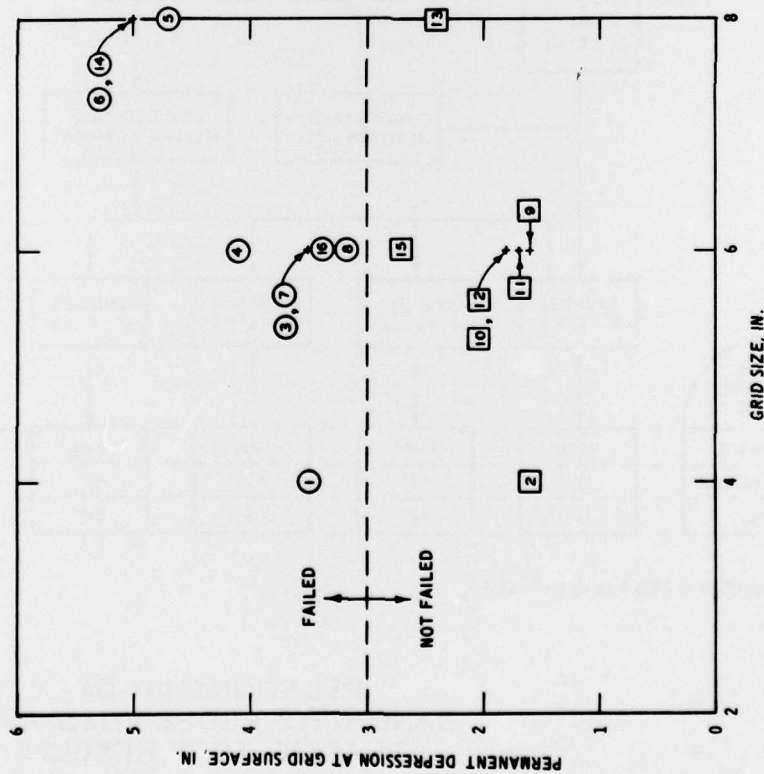
LEGEND

- PERMANENT SURFACE DEPRESSION (IN THE WHEEL PATH)
- RUT DEPTH (PERMANENT SURFACE DEPRESSION PLUS UPHEAVAL OUTSIDE THE WHEEL PATH)

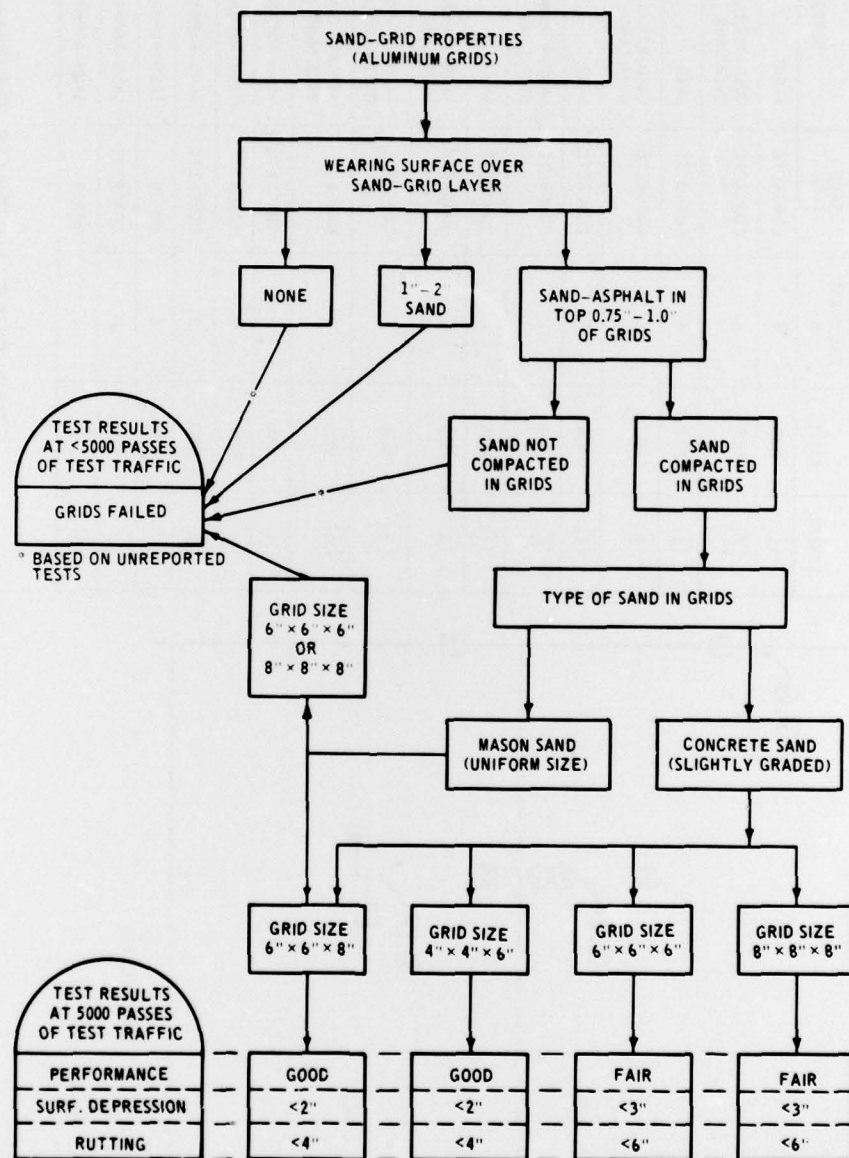
**PASSES VERSUS PERMANENT
SURFACE DEPRESSION AND
RUT DEPTH, TEST SECTION 2
ITEM 5**

LEGEND

SYMBOL	PASSES	GRID THICKNESS IN.	GRID SAND TYPE	SURFACING
①	4850	6	CONCRETE	SAND
②	4850	6	CONCRETE	SAND-ASPHALT OVER SAND
③	2500	6	CONCRETE	SAND
④	2000	6	CONCRETE	SAND-ASPHALT OVER SAND
⑤	600	6	CONCRETE	SAND
⑥	600	6	CONCRETE	SAND-ASPHALT OVER SAND
⑦	4850	8	CONCRETE	SAND
⑧	4850	8	CONCRETE	SAND-ASPHALT OVER SAND
⑨	5000	8	CONCRETE	ASPHALT-FABRIC-MEMB. OVER SAND-ASPHALT
⑩	5000	8	MASON	ASPHALT-FABRIC-MEMB. OVER SAND-ASPHALT
⑪	5000	8	CONCRETE	SAND-ASPHALT
⑫	5000	8	MASON	SAND-ASPHALT
⑬	5000	8	CONCRETE	SAND-ASPHALT
⑭	5000	8	MASON	SAND-ASPHALT
⑮	5000	6	CONCRETE	SAND-ASPHALT
⑯	5000	6	MASON	SAND-ASPHALT

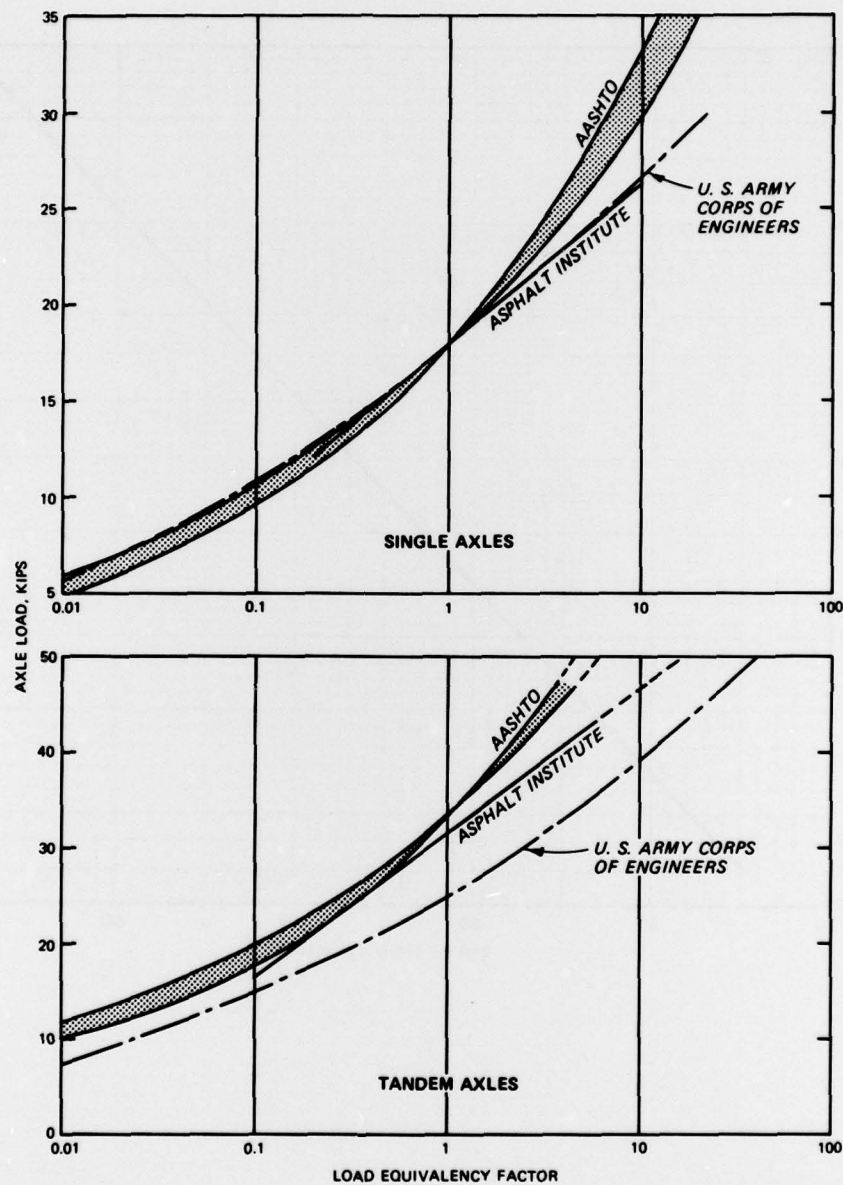


GRID SIZE VERSUS PERMANENT DEPRESSION AT GRID SURFACE

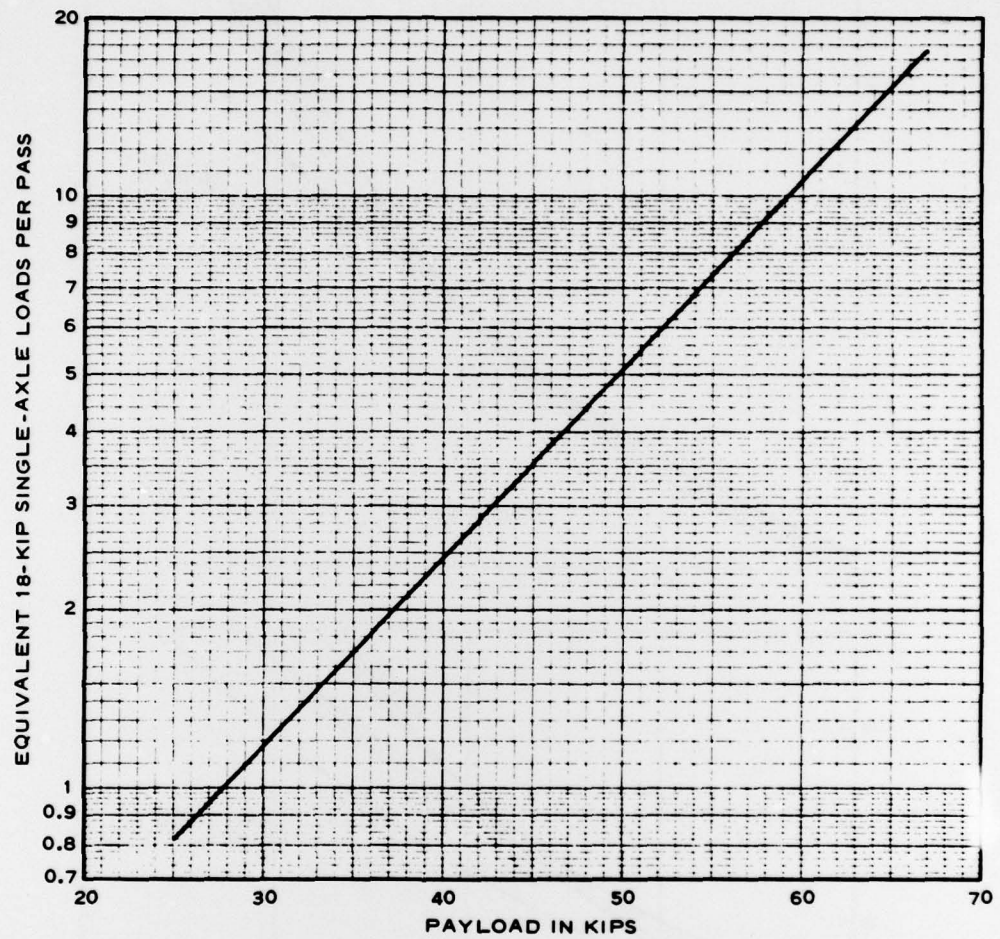


NOTE: LAST NUMBER IN GRID SIZE IS THICKNESS

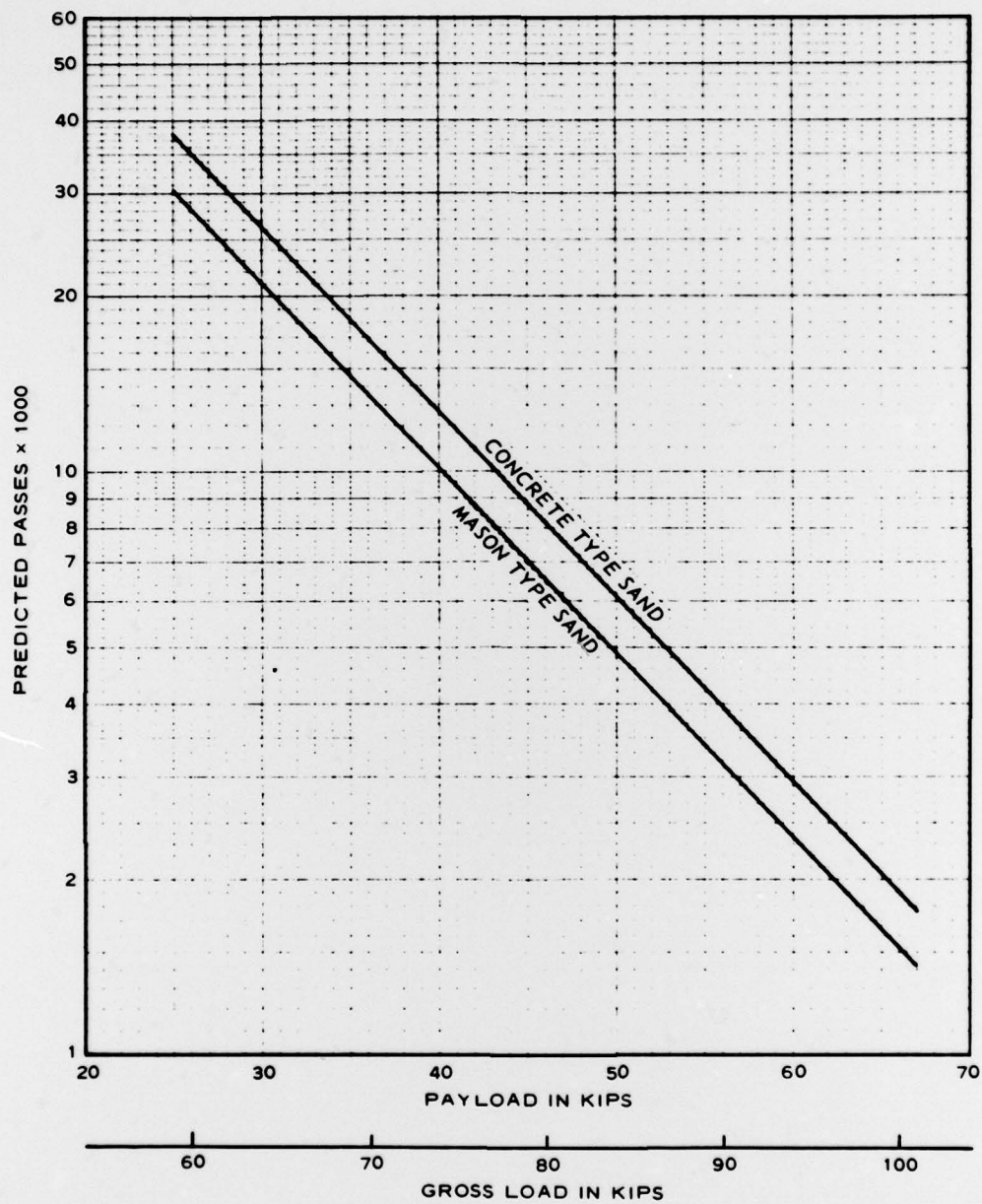
RELATIONSHIP OF SAND-GRID PROPERTIES AND TRAFFIC TEST RESULTS



FLEXIBLE PAVEMENT
LOAD EQUIVALENCY FACTORS
FOR SINGLE AND TANDEM AXLES



**LOAD EQUIVALENCY
INFORMATION FOR
XM 878 TRUCK TRACTOR
XM 872 SEMITRAILER
COMBINATION**



PREDICTED PERFORMANCE FOR
TRUCK SEMITRAILER (XM 878, XM 872)
CONTAINER OPERATIONS
OVER GRID-STABILIZED BEACH SAND

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Webster, Steve L

Investigation of beach sand trafficability enhancement using sand-grid confinement and membrane reinforcement concepts; Report 1: Sand test sections 1 and 2 / by Steve L. Webster. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

35, [35] p., 31 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; GL-79-20, Report 1)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A762719AT40, Task Area CO, Work Units 001 and 004.

References: p. 35.

1. Beach sands. 2. Beach trafficability. 3. Expedient surfacings. 4. Grid confinement. 5. Membranes (Beaches). I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; GL-79-20, Report 1. TA7.W34 no.GL-79-20 Report 1